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GUIDELINES FOR THE TREATMENT OF CAPE COLOURED WATERS

Final Report to the

Water Research Commission

by

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EXECUTIVE SUMMARY

In the southern coastal zones of South Africa, organically coloured surface waters are used as the main source for the supply of drinking water. A lack of information on design of colour removal treatment plants, coupled with operational problems experienced with the treatment of coloured waters, necessitated an investigation into the causes of these problems, from which practical solutions in the form of guidelines for design engineers and operating personnel could be made available. A project to carry out the investigation and draw up the guidelines was consequently undertaken. The project was funded by the Water Research Commission.

The guidelines document aims in particular to address the problems that are experienced with the treatment of coloured waters, of which the more important ones are listed in the document. It therefore has a section where guidelines are given for addressing each of the problem areas, with cross-references to the various unit processes and plant operations.

The document firstly gives an overview of the nature, origin and occurrence of colour in surface waters, and why it is necessary to treat these waters if they are to be used for drinking purposes. A description is then given of the work that was done under the project to investigate treatment practices at treatment plants treating coloured waters in the Cape, and includes a listing of problems that were identified during the survey of the plants and during discussions with water suppliers and consultants.

The different treatment processes that can be used to treat coloured water are discussed in some detail in Chapter 6, and this is followed by a consideration of operational and monitoring requirements for colour removal treatment plants in Chapter 7.

A separate chapter is devoted to the treatment and disposal of sludge produced in colour removal treatment plants.

In Chapter 10 the guidelines for treatment of coloured waters are presented, which includes criteria for the selection of suitable treatment processes, a summary of process configurations, specific guidelines for the different unit treatment

processes employed in colour removal treatment plants, and a list of problems with treatment of coloured waters together with specific guidelines for solving or remedying the problems.

The annexures include a bibliography of references cited and literature for further reading, a summary of plant details for each of the treatment plants that were surveyed, results of some bench-scale tests that were performed, procedures for performing beaker tests, chemicals used in colour removal treatment plants, and needs for further research.

While the project has achieved its aim of providing practical and useful guidelines, to plant-operating personnel in particular, the extent of the project did not allow any in-depth investigation of the chemical treatability of the South African coloured waters by coagulation. At a seminar/workshop (jointly organised by the WRC) that was held in Mossel Bay in October 1996 on ***The Treatment of Coloured Water for Potable Use***, by far the highest priority for further research was found to be the need for characterisation and removal of unwanted organic compounds in coloured waters. Little information is available on the true character and properties of the local coloured waters, and more specifically of its high variability in locality and time (spatial and temporal variation), as well as the many complexes that it forms with other substances, notably metals. There is also a lack of knowledge on the effect of treatment processes, and in particular coagulation, on the removal of the different constituents of the coloured water. This need for further research on organic matter and colour removal was also confirmed at a Technology Transfer Fair on Drinking Water Treatment that was presented by the WRC in Johannesburg during November 1996.

A follow-up project has commenced to characterise South African coloured surface waters and to investigate chemical treatment for removal of organic matter from these waters. The coagulation treatability tests will provide a better understanding of the mechanisms involved in chemically removing the natural organic material and organic complexes. This is of particular importance in enhancing the coagulation process for the removal of organic material, disinfection by-products and metals, and for improving the control of coagulation.

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" Guidelines for the Treatment of Cape Coloured Waters"

The Steering Committee responsible for this project consisted of the following persons:

Dr G Offringa	Water Research Commission (Chairman)
Mr F P Marais	Water Research Commission (Secretary)
Dr H M Saayman	Water Research Commission
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Mr I K Reid	Ninham Shand Inc.
Mr H Basson	George Municipality
Mr H Geldenhuys	Plettenberg Bay Municipality
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Chris Swartz
Mossel Bay

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NOMENCLATURE

In the report, a number of abbreviations, concepts and shortened forms are used in the text, tables and graphs. For easy reference, these abbreviations and shortened forms with their explanations are given below.

coloured water	coloured water, in the context of this document, is defined as any natural water containing organic matter (aquatic humus) which gives rise to a yellow to brown colour of the water
humic substances	materials which constitute the water extractable fraction of soil humus (also called aquatic humus)
colour unit	measurement unit for colour (1 colour unit (CU) = 1 mg/ℓ as Pt = 1 Hazen unit)
apparent colour	direct measurement of colour in a sample (it therefore includes any colour that is caused by suspended matter in the sample)
true colour	the colour of a sample after filtration through a 0,45 micron membrane filter (therefore a measurement of colour in solution)
TOC	total organic carbon
DOC	dissolved organic carbon
THM	trihalomethane
TTHMFP	total trihalomethane formation potential
NOM	natural organic matter

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CHAPTER 1

INTRODUCTION

1.1 NEED FOR GUIDELINES ON THE TREATMENT OF COLOURED WATER

In the southern coastal zones of South Africa, organically coloured surface waters are used as the main source for the supply of drinking water. Treatment of these coloured waters is to a large extent still done empirically, and it seems that there is a lack of knowledge about the character and properties of the water. As a result of this, many problems are experienced with the treatment of coloured waters. Amongst the more potentially serious problems are poor colour removal as a result of underdosing of coagulants when the quality of the raw water changes; wasting of chemicals as a result of overdosing of chemicals and lime by inexperienced operating personnel; high aluminium residuals in the final water to the consumer as a result of poor pH control when dosing aluminium sulphate; discolouration of water caused by iron and manganese precipitates; the formation of undesirable disinfection by-products (notably trihalomethanes) when these waters are chlorinated; the production of large volumes of sludge with poor dewatering characteristics; and ineffective stabilization of the final water leading to corrosive and aggressive attack on the water supply networks.

A lack of information on design of treatment plants, coupled with operational problems experienced with the treatment of coloured waters, necessitated an investigation into the causes of these problems, from which practical solutions in the form of guidelines for design engineers and operating personnel could be made available. A project to carry out the investigation and draw up the guidelines was consequently undertaken.

The project consisted of investigations of full-scale plants in the Southern and Western Cape, discussions with consultants and water suppliers, characterisation of raw waters, and bench-scale tests performed on selected raw waters found in the study area. Specific objectives of the study were:

- to identify problems experienced with the treatment of organically coloured waters found in the southern coastal areas of South Africa;
- to propose practical measures to solve these problems based on a survey of water purification works treating these waters and on comparative bench-scale tests; and
- to draw up guidelines for the treatment of coloured water for potable use in South Africa.

1.2 INTENDED USE OF THE GUIDELINES DOCUMENT

The guidelines document aims in particular at addressing the problems that are experienced with the treatment of coloured waters, of which the more important ones are listed in this document. It therefore has a section where guidelines are given for addressing each of the problem areas.

The guidelines document is available on a national level for use by consulting engineers and local authorities to plan, design and construct water purification plants treating organically coloured waters. The guidelines document will furthermore enable operating personnel at plants to gain a better understanding of the principles involved in treating organically coloured waters.

1.3 STRUCTURE OF THE GUIDELINES DOCUMENT

The document firstly gives an overview of the nature, origin and occurrence of colour in surface waters (Chapter 2), and why it is necessary to treat these waters if it is to be used for drinking purposes (Chapter 3). Chapter

4 then describes the work that was done under the project to identify the problems that are experienced with the treatment of coloured waters in the Cape, and to propose practical measures, in the form of design and operational guidelines, to solve these problems. Chapter 5 lists these problems that are experienced with the treatment of coloured waters in South Africa, that were identified during the survey of treatment plants in the Cape and during discussions with water suppliers and consultants.

In Chapter 6, an overview is given of the treatment processes that can be used to treat coloured water. The conventional treatment processes of coagulation followed by settling, filtration, disinfection and stabilisation are discussed in some detail, while an overview and the results of local research are presented for the technologies such as membrane processes, chemical oxidation (in particular ozonation and combinations thereof) and dissolved air flotation, that are currently finding application in the treatment of coloured water.

Chapter 7 discusses the need for and importance of well-designed operational and monitoring programmes for colour removal treatment plants, and gives recommendations for monitoring programmes for small and larger plants. Chapter 8 lists upgrading considerations for existing colour removal treatment plants.

The issues concerning the treatment and disposal of sludge emanating from colour removal treatment plants are discussed in a separate chapter (Chapter 9).

In Chapter 10 the guidelines for treatment of coloured waters are presented, which includes criteria for the selection of suitable treatment processes, summary of process configurations and specific guidelines for the different unit treatment processes employed in colour removal treatment plants.

CHAPTER 2

COLOURED WATER

2.1 DEFINITION OF COLOURED WATER

Coloured water, in the context of this document, is defined as any natural water containing organic matter which gives rise to a yellow to brown colour. It therefore refers to organically coloured surface waters, and excludes any coloured waters arising from industrial activities.

2.2 NATURE OF ORGANIC COLOUR

Most natural surface waters contain a certain amount of organic matter. The organic matter may be grouped into humic substances and non-humic substances, the former making up the larger part. If these humic substances are present in high concentrations in the water they give rise to a yellow-brown colour (because the humic materials absorb light at short wavelengths). They are resistant to microbial degradation and have the ability to form stable, water-soluble and water-insoluble salts as well as soluble complexes with metal ions and hydrous oxides, making them particularly difficult to remove from surface waters.

The humic substances consist of humic acid, fulvic acid and humin. The humic acids are colloidal in nature with molecular masses of up to 50 000. Humin has molecular masses of up to 800, while fulvic acid has very low molecular masses and is therefore not colloidal but in true solution. Organic colour is hence in true solution, but a proportion of the molecules are large enough to exhibit colloidal properties.

The molecules of humic substances contain stable ring structures and carboxylic acid and phenol groups. Both acidic and phenolic groups react with aluminium and iron salts. The aluminium binding properties of humic materials from different sources vary somewhat.

The molecules become negatively charged by loss of hydrogen ions, rendering them more soluble. Fulvic acids have nearly twice as many acid groups per gram as humic acids and are more hydrophillic. At low pH values the ionisation is lessened, reducing solubility, and vice-versa.

2.3 ORIGIN OF COLOUR IN SURFACE WATERS

The humic substances, also called aquatic humus, constitute the water-extractable fraction of the soil humus. The differences in the physical and chemical properties between humus in soil and humus in water are relatively small, and therefore it is not necessary to consider these as separate groups of organic matter. The organic matter is one or more of the following: plant and animal products in various stages of decomposition; substances synthesized biologically and/or chemically from the breakdown products; and microorganisms and small animals and their decaying remains (Benefield and Jenkins, 1983). The synthesis of humus is thus based on plant residues, and the most important compounds in this respect are lignin, carbohydrates, and proteins.

The formation of humus is dependent on factors such as vegetation, population and activity of microorganisms, and on the hydrothermal conditions (Gjessing, 1976). The physical and chemical properties of the soil are also of great importance, both with regard to the rate of the humification process and to the composition of the humus products. The amount and qualitative composition of this soil organic matter are dependent on the temperature, humidity, chemical, physical, and microbiological activity, and on the mineral composition and the age of the soil. In other words, the processes involved are extremely complex, and it is obvious that the humus in soil is subject to continuous changes and that the composition will vary according to the location.

2.4 MEASUREMENT OF COLOUR

a. Standard units of colour measurement

The colour produced by 1 mg/ℓ of platinum ($K_2PtC\ell_6$) is taken as the standard unit of colour. This is sometimes referred to as colour units (CU), and is also called "degrees Hazen", after A. Hazen.

Hence, 1 mg/ℓ as Pt = 1 colour unit (CU) = 1 degree Hazen (or just Hazen)

Direct measurement of colour in a sample includes any colour that is caused by suspended matter in the sample. It is therefore a measurement of *apparent colour*. To determine the *true colour* of the sample, the suspended matter must be removed, and this is accomplished by filtration of the sample through a 0,45 μm membrane filter and measuring the colour of the filtrate.

The different methods and standard procedures for laboratory and field measurements of colour in water samples are given in Annexure D.

b. Measurement of colour causing substances

A more accurate quantification of colour causing substances in a natural water is to measure the UV absorbance, which is often done at a wavelength of 254 nm. The latest version of Standard Methods (19th Edition, 1995) contains a method for UV determinations. The total organic carbon (TOC) determination measures the total pool of organic material in the sample, with the dissolved organic carbon (DOC) relating to the dissolved fraction thereof. The total trihalomethane formation potential (TTHMFP) gives an indication of the quantity of organic material in the water that has the potential of forming undesirable organohalogens when the water is chlorinated. Although the above measurements are used widely for research purposes, it is not practical to use them for measurement of raw water organic content at the small to medium sized treatment plants for process control purposes.

c. Effect of pH on colour measurement

Colour intensity generally increases with increase in pH. This effect is more prominent at high colour concentrations, and is negligible for concentrations lower than 50 mg/ℓ as Pt.

It has been suggested that colour measurement be standardised at a pH of 8,3, *i.e.* the pH of the sample is to be set to a pH of 8,3 by adding an alkali (sodium bicarbonate), before the colour is determined. However, it is impractical to adjust the pH of coloured water samples for routine analysis, and it is therefore not widely practised.

2.5 OCCURRENCE OF COLOUR IN SOUTH AFRICAN SURFACE WATERS

Coloured surface waters in South Africa are mainly found in the water courses arising on the southern slopes of the Southern and Western Cape coastal mountain ranges. Colour is also found in some surface waters in Mpumalanga, but to a lesser extent.

The high colours found in the Cape waters (up to 1 000 mg/ℓ Pt around George and Mossel Bay) are associated with the Table Mountain sandstone and the unique fynbos found in the area. Coloured water is found along the coastal region from Port Elizabeth in the east up to and including Cape Town in the west.

Table 2.1 gives an indication of colour levels of some raw waters that are treated for potable use in the Cape.

Table 2.1 Colour levels of raw waters at colour removal treatment plants in the Western and Eastern Cape Provinces

Treatment plant	Location	Range or typical value of colour of raw water (mg/ℓ as Pt)
Kloof Nek	On the slopes of Table Mountain in Cape Town	120 - 240
Constantia Nek		120 - 240
Faure	In the area between Kuils River, Somerset West and Stellenbosch	10 - 40
Blackheath		5 - 40
Steenbras	Near Gordons Bay	20 - 140
Rûensveld Wes	North-West of Caledon	30 - 110
Swellendam	Swellendam	160
Duivenhoks	Heidelberg	160 - 650
Riversdale	Riversdale	300
Kleinbrak	Near Mossel Bay	320 - 770
Sandhoogte	Near Mossel Bay	360 - 960
Grootbrak	Great Brak River	250 - 680
George	George	500 - 1100
Wilderness	Wilderness	150
Sedgefield	Sedgefield	350
Knysna	Knysna	60
Plettenberg Bay	Plettenberg Bay	45 - 390
Churchill	Port Elizabeth	10 - 60
Loerie		
Elandsjagt		

CHAPTER 3

REASONS FOR TREATING COLOURED WATER

3.1 OBJECTIONS TO COLOUR IN WATER SUPPLIES

Colour, as is the case with taste, odour and turbidity, forms a primary quality parameter when water is supplied from any raw water source for human consumption. Humans consider clear and colourless water as the minimum requirement when the water is to be used for drinking purposes. This is the case regardless of whether the colour or turbidity has any health implications or not. Organic colour in water is therefore aesthetically unacceptable to the consumer.

Chlorination of waters that contain organic colour leads to the formation of halogen compounds such as chloroform that may be mutagenic and carcinogenic to humans. The organic colour compounds (humics) are trihalomethane (THM) precursors, which would have to be removed if chlorination is to be used for disinfection of the water. Some non-humic organic substances in surface waters are also THM precursors, which implies that the removal of organic colour does not necessarily mean that no THM's will be formed when the water is chlorinated. (Although no standards have (yet) been promulgated in South Africa for THM levels, the American standard of 100 $\mu g/\ell$ is generally used as local guideline).

Organically coloured waters usually have a low alkalinity and low pH, making them corrosive to metal pipes and materials, even to normally corrosion resistant piping such as copper and galvanised pipes and fittings.

The deficiency of carbonate species also makes the water aggressive and leads to increased rates of deterioration of concrete pipes and structures. Stabilization of these waters is essential to protect the water supply network.

Organic compounds in water also serve as nutrient source for microorganisms which can lead to bacterial growth in water purification plants and distribution systems. This results in deterioration of the water quality and slime formation in tanks and pipes, and also leads to biological corrosion.

Organically coloured water requires higher dosages of oxidants such as chlorine for effective disinfection.

3.2 WATER QUALITY GUIDELINES FOR COLOUR AND COLOUR CAUSING SUBSTANCES IN WATERS FOR DRINKING PURPOSES

Public health officials are aware of the fact that consumers will seek other sources of drinking water if the public water supply is not aesthetically acceptable, no matter how safe it may be from the hygienic viewpoint. Where these waters are not aesthetically acceptable, consumers often reject safe domestic supplies and use waters from uncontrolled springs or boreholes which may be polluted and contain pathogenic organisms.

For this reason, it is widely accepted that waters intended for human use should not have a colour exceeding 15 mg/ℓ as Pt (this being the level where the appearance of the yellow-brown colour of water in a container, *e.g.* a bathtub, becomes visible and unacceptable to the consumer).

The following limits for colour and colour causing substances in water for drinking purposes have been recommended:

South African Bureau of Standards (SABS) specifications for drinking water: SABS 241 of 1984

Recommended limit for colour	20 mg/ℓ as Pt
Maximum allowable	No value given
Recommended limit for DOC	No value given
Maximum allowable DOC	No value given

World Health Organisation (WHO) standards for drinking water

Recommended maximum colour concentration	15 mg/ℓ as Pt
Recommended maximum DOC	No value given

Department of Health Water Quality Guidelines

Recommended limit for colour	20 mg/ℓ as Pt
Negligible risk limit for colour	No value given
Low risk limit for colour	No value given
Recommended limit for DOC	0,5 mg/ℓ
Negligible risk limit for DOC	10 mg/ℓ
Low risk limit for DOC	20 mg/ℓ

3.3 EFFECT OF UNDESIRABLE CONSTITUENTS IN COLOURED WATER

The main effects of undesirable constituents in coloured waters, and the reasons why these waters require treatment in order to render them safe and acceptable for drinking purposes, are given in Table 3.1.

Table 3.1 Effect of undesirable constituents in coloured water

Constituent	Effect
Colour (natural organic matter) (humic substances)	1. Aesthetically unacceptable to consumers 2. THMs are formed when water with organic colour (humic substances) is chlorinated 3. The colour-causing organic compounds serve as nutrient source for microorganisms and cause bacterial growth 4. The water has a higher oxidant (chlorine) demand
Pathogens	All surface water sources potentially contain pathogenic organisms which have to be killed by disinfection to render the water safe for human consumption
Aluminium	Chronic high levels of aluminium in drinking water are suspected of possibly being associated with the occurrence of Alzheimer's Disease Aesthetic problems (dirty water in distribution network)
Iron and manganese	Iron and manganese in tap water cause staining of laundry and fixtures, and impart a metal taste to the water
Low pH Low alkalinity Calcium species deficiency	Corrosiveness to metallic elements Aggressiveness to cement-based elements

CHAPTER 4

SURVEY OF COLOUR REMOVAL TREATMENT PLANTS IN THE SOUTHERN AND WESTERN CAPE

An investigation of full-scale treatment practices in South Africa was done by visiting a number of purification plants in the Southern and Western Cape treating coloured water. The investigation more specifically consisted of:

- a survey of the plants to establish capacities, processes employed, chemicals used, design parameters (where available), and monitoring practices
- discussions with operators/supervisors about the problems experienced with treating the organically coloured water
- obtaining raw water data where available

A total of 18 treatment plants were visited. Details of the plants that were visited appear in Annexure B.

4.1 CHARACTERISATION OF RAW WATER

The quality of the coloured surface waters in the study area on the Cape south coast varies considerably, both in terms of colour levels and other properties such as turbidity, alkalinity and acidity, and iron and manganese content. The apparent colour of the water ranges from about 20 - 40 mg/ℓ Pt near Cape Town (Theewaterskloof Dam) and in Port Elizabeth, to a maximum of around 500 - 1000 mg/ℓ Pt at George. In most of the water sources the colour is in true solution, so that the true colour is almost as high as the apparent colour. The turbidities of the coloured waters are normally low (less than 5 NTU), but in some of the raw waters moderate turbidities of up to 20 NTU are found, while the water in the Duivenhoks River has reached turbidity levels as high as 400 NTU on occasions. The alkalinities of the waters are generally low (less than 5 mg/ℓ as $CaCO_3$), with the exception at Plettenberg Bay where the alkalinity ranges between 18 and 29 mg/ℓ as $CaCO_3$. Some of the surface waters contain moderate to high quantities of iron (0,5 - 2,0 mg/ℓ), which requires that provision should be made in the treatment process for removing it (possibly by raising the pH and dosing chlorine before the filters).

Based on the characterisation of the coloured waters found in the southern coastal areas of South Africa, a classification for South African coloured waters is proposed which not only categorises the water according to the colour concentration, but also according to turbidity and iron content. The ranges that are proposed for the colour, turbidity and iron in each category are chosen according to the treatability of the water with conventional treatment methods. The proposed classification is shown in Table 4.1.

4.2 TREATMENT PRACTICES

All the plants that were visited are municipal treatment plants, with the exception of two plants which are owned and operated by Overberg Water. They range in size from 2 Mℓ/day to the new 500 Mℓ/day plant at Faure outside Cape Town. The majority of the smaller treatment plants are older plants that have been in service for some years. New treatment plants include the Faure plant and George new works, while the Sedgefield and Knysna treatment plants have recently been upgraded.

Table 4.1 : Proposed classification of coloured waters in South Africa

CHARACTERISTIC	LOW	MEDIUM	HIGH
Colour (mg/ℓ as Pt)	< 30 *Can be treated by coagulation, flocculation and direct filtration as the only separation process*	30 - 200 *Sedimentation step required before filtration*	> 200 *High chemical dosages required*
Turbidity (NTU)	< 5 *Can be treated by direct filtration*	5 - 20 *Direct filtration or flotation can be used*	> 20 *Additional sedimentation step required before filtration*
Iron (mg/ℓ as Fe)	< 0,3	0,3 - 1,0	> 1,0

For example, a water source with a colour of 300 mg/ℓ Pt, turbidity of 3 NTU and iron concentration of 0,5 mg/ℓ will be classified as a HIGH COLOUR, LOW TURBIDITY, MEDIUM IRON WATER.

At each of the plants surveyed, an assessment of the treatment practices was done through: visual observations; discussions with plant operators and/or plant managers; obtaining data on raw water quality, chemical dosages and design parameters; and consultation of reports on plant design or construction (where applicable and available). <u>The results of these assessments are integrated into Chapters 6 to 9 of this document.</u>

Information on the plant capacity, raw water quality and processes employed for each of the 18 plants surveyed is given in Annexure B.

All the treatment plants use the conventional colour removal process of chemical precipitation, consisting of coagulation with pH adjustment, flocculation, settling and sand filtration, with disinfection and stabilization as final treatment steps.

4.3 BENCH-SCALE TESTS AND PLANT DATA ANALYSIS

After a broad characterisation of coloured waters found in the study area, four treatment plants were selected to represent the various raw water qualities encountered. Comparative bench-scale tests and plant data analysis were performed for these plants. The selected plants were Blackheath (Cape Town Municipality), Duivenhoks near Heidelberg (Overberg Water), Sandhoogte (Mossel Bay Municipality) and Kleinbrakrivier (Mossel Bay Municipality). The chemical qualities of the raw waters supplying these plants are shown in Table 4.2.

Bench-scale tests were done to establish or confirm certain design criteria or optimum treatment conditions related to the treatment of coloured water. These tests consisted of coagulation beaker tests at Sandhoogte and Kleinbrakrivier, with analysis and correlations of plant data (beaker tests done by plant personnel and full-scale operational data) at the other two selected plants.

The beaker tests included a comparison of primary coagulants for colour removal; establishment of pH ranges for effective coagulation for each of these primary coagulants; effect of order in which chemicals are dosed; and floc settleability under various coagulation conditions.

The results of the bench-scale tests are summarised in graphs in Annexure C, and conclusions therefrom are integrated into Chapters 6 and 7 as guidelines for coloured water treatment.

Table 4.2 Chemical quality of raw waters feeding representative colour removal treatment plants in the Cape (long-term records)

QUALITY PARAMETER	TREATMENT PLANT			
	Blackheath	Duivenhoks	Sandhoogte	Kleinbrak
Apparent colour (mg/ℓ as Pt)	-	160 - 650	366 - 960	322 - 770
True colour (mg/ℓ as Pt)	< 5 - 40	-	150 - 886	45 - 487
UV Absorbance	0,090 - 0,606 (300nm 4cm)	-	2,38 - 4,33 (*) (254nm 4cm)	-
DOC (mg/ℓ)	-	-	8 - 25 (*)	-
Turbidity (NTU)	0,86 - 20	2 - 400	0,50 - 2,2	6,9 - 45
pH	6,3 - 8,1	4,1 - 6,5	3,2 - 5,3	3,7 - 7,7
Alkalinity (mg/ℓ as $CaCO_3$)	2 - 10	2 - 28	0 - 0,8	0 - 52
Calcium (mg/ℓ as Ca)	1,2 - 5	4 - 30	1,6 - 25	4 - 32
Magnesium (mg/ℓ as Mg)	0,5 - 2,9	1,0 - 8,3	1,0 - 4,1	1,7 - 16,5
Conductivity (mS/m)	3 - 11	8 - 70	5 - 14	7 - 55
Chloride (mg/ℓ as Cl)	7 - 21	20 - 94	5 - 103	25 - 179
Iron (mg/ℓ as Fe)	0,07 - 1,6	0,46 - 1,42	0,30 - 0,85	0 - 9,2
Manganese (mg/ℓ as Mn)	0 - 0,36	0,07 - 0,13	0 - 0,18	0 - 0,76
Aluminium (mg/ℓ as Al)	0,24 - 1,20	0,04 - 0,16	0,58 - 0,89 (*)	0,37 - 3,8(*)
Raw water classification	Low colour Medium turb. Medium iron	High colour High turb. Medium iron	High colour Low turb. Medium iron	High colour High turb. High iron

(*) Occasional measurements

Analysis of plant data

Data collected by plant personnel over a period of time at the four selected plants were analysed and correlated with chemical dosages and other operational variables to enable establishment of trends or curves that can be used for certain aspects of the design or operation of colour removal treatment plants, *e.g.* dosage curves for coagulation control.

The results of this plant data analysis are also integrated into Chapters 6 and 7 as part of the development and presentation of guidelines for the treatment of coloured water.

4.4 IDENTIFICATION OF PROBLEMS WITH THE TREATMENT OF COLOURED WATER

During the survey of treatment plants, the major problems experienced with the treatment of organically coloured water were identified. These are listed in Chapter 5, and each problem is addressed in Chapters 6 to 9, where guidelines are given that will, amongst other, also reduce or eliminate them. In Chapter 10, guidelines are given for the design and operation of the different unit treatment processes, and measures or remedies proposed for the problems or potential problems that are experienced at colour removal treatment plants.

CHAPTER 5

PROBLEMS EXPERIENCED WITH THE TREATMENT OF COLOURED WATER

From the survey of water treatment plants in the Western and Southern Cape (as described in Chapter 4), local project reports and international literature, the following were identified as the major potential problems experienced with treatment of organically coloured waters:

1. In the majority of the smaller treatment plants in the study area the quality of the raw water is not quantified, and in most of the cases not monitored on a regular basis either. Large changes in raw water quality (in particular colour) are therefore only detected much later when the quality of the final water becomes unacceptable. Adjustments to dosages are then done empirically, and by the time that the processes once again produce effective floc formation and removal and a good quality water, large quantities of coloured water have been produced which reach the consumer or have to be discarded. Hence, there is a need for dosage curves whereby coagulant dosages can be adjusted more accurately according to measured raw water colour.

2. Flocs that are formed in the flocculation process are light and are easily ruptured. The flocs do not settle readily and floc carry-over from settling tanks to filters may take place. Poor filter design, backwash operation or settlement may result in flocs passing through the filters and entering the finished water supply.

3. In open sedimentation tanks, wind action and the uneven heating of the water mass cause the floc to rise and have a detrimental effect on the efficiency of the sedimentation process.

4. When poor settling is experienced as a result of one or more of the reasons mentioned above, the coagulant is often overdosed. This leads to higher chemical costs, shorter filter runs and increased sludge volumes.

5. In general, when alum is used as coagulant, high aluminium concentrations can occur in the final water when the pH at which the raw water is coagulated is not carefully controlled, even when the alum is not being overdosed. A possible association between aluminium levels in drinking water and Alzheimer's disease has been suggested, which has resulted in a negative public perception towards the use of alum in water treatment plants. Furthermore, when residual aluminium accumulates in the distribution system, particularly where flows are low, it forms deposits on pipe surfaces together with iron, manganese and silica. These deposits may readily be disturbed by changes in flow and appear at the consumer tap, making the water aesthetically unacceptable.

6. A variety of designs are used for horizontal settling tanks, especially with regard to the inlet and outlet arrangements, with varying degrees of success. Floc removal by settling is therefore in many instances poor, resulting in high floc loadings on the filters, which in turn leads to short filter runs and poor quality of final water.

7. Poor removal of iron and manganese can lead to high levels of these metals in the final water, giving taste problems and staining of laundry. If an iron salt is used as coagulant and low coagulation pH levels maintained for optimum colour removal, then high iron levels may occur in the filtered water unless the iron is precipitated by raising the pH before filtration and removing the precipitate by the sand filters.

8. Water needed for filter backwashing can constitute a sizeable percentage of the plant's treatment capacity. Air scouring is also not done at all the plants. As a result, filters do not perform optimally, and there is a need for further investigation to model the behaviour of filters treating organically coloured water.

9. Biological growth sometimes occurs in settling tanks and filtration systems and leads to periodic breakthrough and subsequent reduction in quality of the final water.

10. The formation of THMs when waters with residual colour are chlorinated can be a cause of concern. Even when the attainment of an almost complete removal of the colour is achieved, a substantial amount of organic material continues to remain in solution.

11. In most of the treatment plants, the water is only partially stabilized by dosing just enough lime to reach a certain pH (usually 9.0 - 9.2). Because the effects of corrosion and aggression take a number of years to become apparent, the connection between the stability of the water and its corrosive and aggressive effects is lost, and it is often wrongfully perceived that the cost of replacing pipes and structural elements is compensated for by the savings of high running costs through not having to dose carbon dioxide.

12. Overstabilization of final water leads to deposits in pipes (scaling) and pipe-narrowing, and to higher pumping costs.

13. Problems are experienced with the quality of the lime used, and a lack of information leads to wrong conceptions as to the most suitable source to use.

14. There have been cases where water from consumer taps in the study area has turned blue or green when certain types of soap or detergent are used. This is associated with the corrosiveness of the water to copper pipes and hot water elements.

15. At a fair number of the plants the procedure for measuring the pH of these waters with low buffer capacity, as well as the operation and maintenance of the pH measuring apparatus, is not consistent and gives rise to large fluctuations in the actual coagulation and stabilisation pH levels. This results in either poor colour removal, overdosing of chemicals to achieve adequate colour removal, and/or underdosing or overdosing of lime for stabilization. There is a need for guidelines on standardisation of pH measurement and on the use of pH meters.

16. Treatment of coloured waters by the conventional chemical precipitation and phase separation processes (*i.e.* coagulation, settling and filtration) leads to the production of large volumes of sludge with poor dewatering characteristics, and subsequent disposal problems.

CHAPTER 6

TREATMENT PROCESSES FOR THE TREATMENT OF COLOURED WATER

Treatment of coloured water normally consists of the following main processes:

REMOVAL OR REDUCTION OF COLOUR CAUSING SUBSTANCES AND SUSPENDED MATTER

DISINFECTION

STABILIZATION

SLUDGE TREATMENT AND DISPOSAL

Depending on the quality of the raw water source, it can also include the removal of iron and/or manganese, and taste and odour removal.

The main treatment processes and unit treatment processes which it consist of are discussed further in this chapter under the following headings:

6.1 REMOVAL OR REDUCTION OF COLOUR CAUSING SUBSTANCES AND SUSPENDED MATTER

6.1.1 Chemical Precipitation

a. **Coagulation**

- Type of coagulant
- Coagulant dosage
- pH adjustment
- Presence of turbidity
- Coagulant residuals
- Rapid mixing
- Control of coagulation process

b. **Flocculation**

- Flocculation systems
- Flocculation agents
- Design aspects

6.1.2 Phase Separation

a. **Settling**

- Types of settling
- Settling rates and retention time
- Effect of temperature and wind on settling
- Materials of construction

b. **Dissolved air flotation**

c. **Filtration**

- Rapid sand filtration
- Direct filtration
- Direct series filtration
- Slow sand filtration

6.1.3 Membrane Processes

6.1.4 Oxidation Processes

a. Ozone

b. Ozone in combination with hydrogen peroxide and/or UV radiation

c. Ozone followed by biological activated filtration

d. Other advanced oxidation processes

6.1.5 Adsorption

6.2 DISINFECTION

a. Chlorine

b. Chlorine dioxide

c. Ozone

d. Other methods of disinfection

6.3 STABILIZATION

a. Aggresion

b. Corrosion

c. Chemical treatment

6.4 SLUDGE TREATMENT AND DISPOSAL

6.1 REMOVAL OR REDUCTION OF COLOUR CAUSING SUBSTANCES AND SUSPENDED MATTER

The colour causing substances in the water can be partly or wholly ***removed*** by:

- chemical precipitation followed by phase separation (settling/flotation/filtration)
- membrane processes

The concentration of the substances can be ***reduced*** by:

- oxidation followed by phase separation and/or adsorption

Chemical precipitation (or simply referred to as coagulation) followed by phase separation is the treatment configuration most widely used for treating coloured water, and is presently still used without exception in South Africa.

In the continuing trend towards the use of less or no chemicals in water treatment, because of health and environmental considerations, attention has in recent years been focussed on membrane processes for removal of natural colour from drinking water sources, both locally and overseas.

Oxidation processes for breaking down the complex colour-causing organic substances and thereby reducing the colour of the water are also an alternative to conventional chemical treatment. Because the simple (short-chain) substances that are formed are more amenable to biological degradation, the process configuration of oxidation followed by biological filtration is also currently the topic of research and process development in view of the potential benefits of reducing the quantity of chemicals used to produce a potable water.

The above main treatment systems that can be employed for colour removal are considered in more detail in the ensuing sections.

6.1.1 CHEMICAL PRECIPITATION

Chemical precipitation consists of destabilising the colour particles by coagulation, aggregating the destabilised particles into larger flocs by some means of flocculation, and removing the flocs formed by settling (or dissolved air flotation) and filtration.

a. Coagulation

Coagulation is the most important process in the removal of colour by phase separation. In this process a chemical is added to the raw water to destabilize the negatively charged colour particles and allow the formed complexes to aggregate into flocs that can subsequently be removed by settling and filtration. The floc formation can be accomplished by one of a number of mechanisms, depending on the pH and coagulant dosage. More detailed information on the coagulation process in the treatment of coloured waters can be found in the literature listed in Annexure A.

Type of coagulant

The following chemicals are most commonly used as coagulants for colour removal:

- Aluminium sulphate (alum)($A\ell_2SO_4.nH_2O$)
- Iron salts
  - ferric sulphate ($Fe_2(SO_4)_3$)
  - ferric chloride ($FeC\ell_3$)
- Polyaluminiumchloride ($PAC\ell$)
- Sodium aluminate ($NaA\ell O_2$)(normally used in conjunction with alum)

Information and properties of these and other chemicals used in colour removal treatment plants are given in Annexure G.

Coagulant dosage

Coagulation beaker tests were done on Sandhoogte and Kleinbrak raw water to compare the efficiency and appropriateness of these coagulants for colour removal in water containing high colour concentrations. The results of these tests are summarised in Table 6.1, which also includes conclusions from literature and discussions with plant operators.

From the results of beaker-tests and plant data analysis, typical coagulant dosage curves were drawn up for the main types of coagulants that are used for treating raw waters at some of the colour removal treatment plants in the Cape. The curves are presented on the same graph in Figure 6.1.

Procedures for performing beaker tests are given in Annexure E.

pH adjustment

As organically coloured waters are usually poorly buffered, the pH of the water after the addition of a chemical for destabilization of the colour particles is normally lower than the pH range for optimum colour removal.

It is therefore necessary to raise the pH of the raw water so that the pH of the coagulated water falls within the optimum range for the particular coagulant used, otherwise poor colour removal will result.

The pH of the raw water is normally increased by the addition of any of the following chemicals prior to dosing of the coagulant:

- lime
- sodium carbonate (soda-ash)
- sodium hydroxide.

Table 6.1 Comparison of coagulants used in South African colour removal plants

	Alum	Ferric sulphate	Ferric chloride	PACℓ
Optimum pH range (beaker tests)	4,8 - 6,5	3,8 - 5,0	4,0 - 5,0	4,0 - 6,0
Optimum pH range (literature)	5,0 - 6,5	4,0 - 5,0	3,7 - 4,5	4,0 - 7,0
Typical dosages for removing high colour (> 600 mg/ℓ Pt)	120 - 220 mg/ℓ	90 - 180 mg/ℓ as $Fe(SO_4)_3$ 25 - 50 mg/ℓ as Fe	75 - 150 mg/ℓ as $FeCl_3$ 25 - 50 mg/ℓ as Fe	Not effective for medium to high colour removal
Aesthetical effects of high metal residuals in final water	When filtered water containing high Al residuals is stabilised at pH 9,0 or higher, the Al redissolves and no discolouration takes place. However, the dissolved Al has health effects (see below)	One of the major problems with using iron salts as primary coagulants in colour removal plants is discolouration of the water caused by iron residuals in the final water. Dissolved iron passing through the filters when chlorination and/or pH adjustment are not performed before filtration, will be oxidised during final chlorination and stabilization and precipitate in the distribution network, causing discolouration at consumers		The same applies for PACℓ as for alum
Health effects of high metal residuals in final water	High aluminium levels in the final water are suspected of possibly being associated with Alzheimer's disease	Iron residuals at levels normally found in treated water do not have any health effects. Only at levels of 5 mg/ℓ as Fe or higher does it pose a health effect		The same applies for PACℓ as for alum
Dosing equipment (tanks, pipes, dosing pumps) requirements	May use stainless steel or plastics	May use stainless steel or plastics	All materials should be rubber or plastic (PVC) (no metals should be used)	May use stainless steel or plastics
Effect on type of lime that can be used before filtration for removal of metal residuals in the filters	Brown lime cannot be used before filtration because raising the pH to 9,0 to remove the impurities in the lime by sand filters will redissolve the Al compounds and result in Al in the final water	Brown lime may be used before filtration because the impurities in the lime may be removed in the sand filters by raising the pH to 9,0 ahead of the filters. Any residual iron is then also removed		The same applies for PACℓ as for alum
Temperature	Because extreme temperatures are not normally experienced in the Cape or only for short periods, the effects of temperature on the efficiency of coagulants are of secondary inportance to the other factors in the selection of the best coagulant			
Delivered as	Powder/granules (now also liquid)	33 % m/m liquid	43 % m/m liquid	Liquid
	See Annexure F			
Cost	Costs of the primary coagulants vary considerably depending on the quantity delivered, transport costs, availability and market forces, and the other factors above normally play a more important role in the selection of the most suitable coagulant for a specific treatment plant			

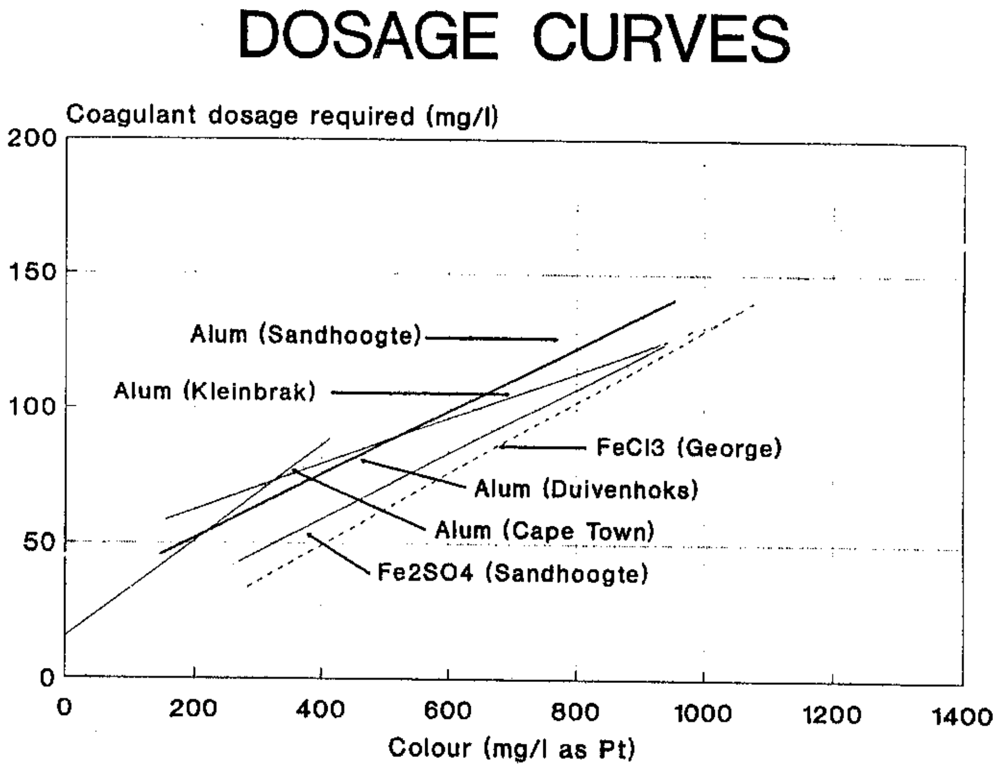


Figure 6.1 Example of coagulation dosage curves for some Cape coloured waters

Although the dosage of lime is the more troublesome (unpleasant to handle; dries the skin; causes throat, lung and skin irritation; precipitates calcium carbonate which may cause blockages) of the above three chemicals, it is most widely used because of economic considerations.

In the 18 full-scale plants surveyed, all but two use lime for pH-adjustment.

The quality of the lime varies considerably from supplier to supplier and also over time from the same suppliers. This inconsistency in the quality of lime supplied to water treatment works in the Western and Southern Cape is currently one of the more serious problems for the water suppliers.

The supply of lime to water treatment plants in the Southern and Western Cape was investigated with respect to quality. The results of the investigation are included in Annexure F (Chemicals used in colour removal treatment plants).

At 10 of the plants, lime is dosed before the coagulant in the mixing race, while at 4 of the plants, the coagulant is dosed followed by lime dosage downstream in the mixing race. At the Plettenberg Bay Water Treatment Plant the point of alum dosage is varied according to the pH of the raw water; when the pH of the raw water is low, lime is dosed first followed by alum; when the pH of the raw water is higher, alum is dosed first.

In coagulation beaker tests done on Sandhoogte raw water it was found that:

- better colour removal is achieved when lime is dosed before alum or when lime and alum are dosed simultaneously, than the case where alum is dosed first followed by lime dosage
- as expected, higher dosages of soda-ash than lime are required to achieve optimum coagulation conditions for colour removal
- ferric-sulphate requires considerably higher dosages of pH adjustment chemicals to obtain optimum coagulation conditions than is the case for alum.

Presence of turbidity

In beaker tests it was found that the optimum pH and dosage ranges for colour removal were unchanged by the turbidity of the raw water.

This is also confirmed by the findings of Edwards and Amirthrayah (1985) and Tambo and Wang (1993) that colour removal from waters with and without turbidity occurred in the same ranges of pH and coagulant dosage.

Coagulant residuals in the final water

Aluminium:

Internationally, the current maximum limit of aluminium in drinking water of 200 μg/ℓ has been adopted by a wide range of regulatory agencies including European Community Directive (1980), WHO (1984) and US Environmental Protection Agency (1991). This value of 200 μg/ℓ is not based on health grounds but rather on aesthetic reasons as the deposition of aluminium flocs in the distribution system after treatment can result in dirty water problems. When residual aluminium accumulates in the distribution system, particularly where flows are low, it forms deposits with iron, manganese and silica. These deposits may be disturbed by changes in flow and appear at the consumer tap, rendering the water aesthetically unacceptable. The present limit is thought to be an adequate safeguard to health by most authorities (Suet-mei, H. and Wing-shiu, T., 1992).

Because of the concern over, in particular, the health implications of aluminium in the final water to the consumer, it has become standard practice overseas not to adjust the pH to the range where only best colour removal takes place, but to adjust the coagulation pH in such a way that the aluminium concentration in the final water is also minimized at the same time.

The optimum coagulation pH to give minimum aluminium residual in the final water depends on the composition of the raw water, but is generally in the range 5,5 - 6,5. This is somewhat higher than the optimum range for colour removal (5,0 - 5,5 for highly coloured waters; 5,5 - 6,0 for low colour concentrations). However, even waters with the same colour do not behave in exactly the same manner when coagulants are dosed and may have different pH ranges at which the aluminium in the final water is minimized. It is therefore necessary to draw up aluminium solubility curves for every coloured water source where alum or PACℓ are used as primary coagulant.

Graphs are plotted, for the specific raw water being treated, of aluminium concentrations measured at different pH values (in coagulation tests with alum), to determine the optimum pH value for minimum aluminium in the final water.

The Cape Town Municipality flocculates at a pH of 5,7 - 6,5 in their water treatment plants that use alum as coagulant to ensure that the aluminium concentration in the final water is minimised.

To reduce the aluminium concentration in the treated water, it is proposed that all treatment plants using alum as coagulant should maintain a coagulation pH of 5,5 to 6,5, even though this may require higher alum dosages to remove colour effectively in plants treating highly coloured water. Alternatively, coagulation can be performed at the optimum pH for colour removal, and additional lime can be dosed just ahead of the filters to precipitate most of the remaining aluminium after settling, as is practised at the George treatment plant. This will, however, increase the load on the filter.

It can be mentioned that, generally, in water treatment plants in the USA, the coagulation pH is never less than 6,0, because of the aggression of the low pH waters on concrete surfaces such as flocculation channels and settling tanks (although it should be noted that the pH of these raw waters are generally higher than those found in coloured waters in South Africa). However, it has become common practice to coat concrete tanks with protective coatings (*e.g.* bitumen).

Iron:

When iron salts are used as coagulants for the treatment of coloured water, the potential also exists that high iron residuals can be found in the final treated water. The optimum pH range for colour removal when using iron salts are normally low (see Table 6.1), and a significant quantity of iron may stay in solution and pass through the sand filters. If this water is then chlorinated for disinfection before distribution, it readily oxidises the soluble iron and causes it to precipitate.

The presence of high iron concentrations in the drinking water distributed to the consumer poses predominantly aesthetic problems. The insoluble ferric hydroxide which precipitates settles out as a rust-coloured silt. As a result of this, an insidious accumulation of iron (and manganese) deposits occurs in the water supply distribution system. This may continue over many years without noticeable problems, but any situation that causes a change in steady state flow conditions will mobilise the deposits resulting in many complaints of discoloured water. Flushing, burst mains and flow reversals are typical changes that mobilise deposits.

Such waters taste unpleasant, and cause aesthetic problems such as staining of plumbing fixtures and laundry. The taste threshold for ferrous iron is approximately 1,0 mg/ℓ. Aesthetic problems such as staining of fixtures and laundry occur above 0,3 mg/ℓ as Fe. This may be aesthetically unacceptable to large sections of the community served, but has no health implications. Only at high concentrations of iron (10 mg/ℓ as Fe or more) does the health effects become significant. The extremely unpleasant metallic taste of the water with these high iron levels would probably prevent consumption (Department of Water Affairs and Forestry, 1993: South African Water Quality Guidelines, Volume 1 - Domestic Use).

To prevent high iron concentrations in the final water would require that the settling and filtration processes be optimised to perform efficiently, and good control of the pH before the filtration step. Raising the pH before the filters to 7,5 or higher by the addition of lime or sodium carbonate will result in most of the iron being precipitated and removed by the filters.

Rapid mixing

Rapid mixing refers to that stage in the overall coagulation-flocculation process where coagulant chemicals are added into the stream to be treated. The function of rapid mixing should not be considered to be one merely of efficient coagulant dispersion. The rapid mixing stage is possibly the most important operation in the process, especially when treating coloured water, since it is here that destabilization reactions occur and where primary floc particles are formed, the characteristics of which markedly influence subsequent flocculation kinetics.

There are two main types of rapid mixing devices, namely back-mix reactors and plug-flow systems. The basic characteristic (and in many instances the shortcoming) of back-mix devices (normally mechanical agitation devices) is that the particles within them have a distribution of residence time. That is, some of the particles will be short-circuited out almost immediately whereas some will stay in the reactor for longer periods than the nominal retention time. In the case of an adsorptive mechanism of destabilization using metal coagulants (like colour removal at certain pH ranges), this can be undesirable for the following reasons:

- due to long residence times extensive hydrolysis of some of the applied metal coagulant to the relatively inefficient Fe $(OH)_3$ or $A\ell(OH)_3$ will take place

- poor overall destabilization of the particles will occur due to either incomplete or extensive adsorption of metal hydroxide species.

Vrale and Jorden (1971) therefore concluded that a plug-flow reactor (pipe, weir or mixing race) is most suitable where adsorptive mechanisms of destabilization are applicable.

Notwithstanding the fact that, depending on the pH of coagulation, the mechanism of destabilization of colour particles can be either precipitation or adsorption, plug-flow mixers have been found to be the most effective for the treatment of Cape coloured water (Reid, 1986).

The following rapid mix units, all of which approximate plug flow mixers, are used in the Cape colour removal plants that were surveyed:

- overflow weir (hydraulic jump)
- baffled mixing race
- orifice plate in a pipe.

These plug-flow mixers are shown in Figure 6.2.

Design aspects

Velocity gradient

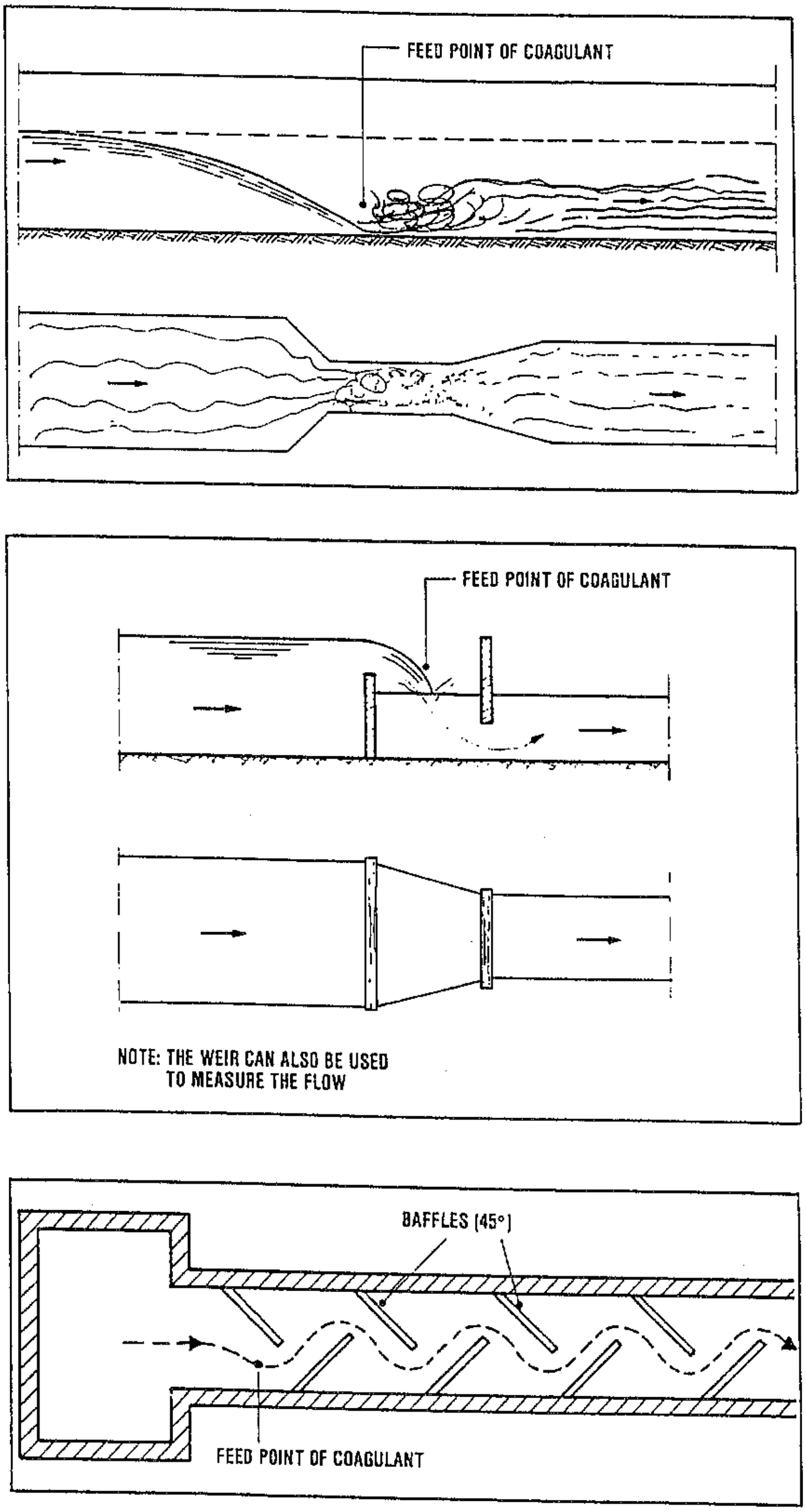
- With a plug-flow rapid mix unit, using a hydrolysing metal coagulant, the range of appropriate G values appears to be from 1200 to 2500 s^{-1} (Vrale and Jorden, 1971).

- Reid (1986) reports that good results were achieved in a new treatment plant treating coloured water using an orifice plate sized to produce a velocity gradient of 250 s^{-1}.

Rapid mix retention time

- Contradictory claims as to optimum rapid mix periods to be used lead Bratby (1980) to conclude that the choice of a suitable rapid mix period to be used for design is somewhat complicated, and that for surety in the final design, laboratory scale and/or pilot scale studies need to be conducted using the particular water under test.

- Reid (1996) showed that the time period required for hydrolysis of the hydroxide is extremely short (less than 1 sec.) and is dependent on the pH and concentration of the coagulant. Regardless of which species are involved in the colour removal mechanism, he concluded that it is logical that the rapid mixing must be done in as short a time as possible.



NOTE: THE WEIR CAN ALSO BE USED
TO MEASURE THE FLOW

Figure 6.2 Plug flow mixers used in colour removal treatment plants

Typical retention times in a back-mix reactor are in the order of 30 sec. to 1 minute. This is clearly to long to accord with the theory. The time of mixing in the plug-flow mixer will depend on the flow velocity and the length downstream of the constriction over which the headloss occurs. The plug-flow unit will clearly offer the best possibility of achieving a short mixing time.

In the coagulation beaker tests it was found that better colour removal was achieved at a rapid mixing time of 3 minutes than 2 minutes.

Tapered rapid mix velocity gradient

- There should be a gradual decrease in velocity gradient from the rapid mix stage to the flocculation stage, as a sharp decline in velocity gradient can have a detrimental effect on subsequent (final) water quality. Morrow and Rausch (1974) found that if rapid mix velocity gradients were suddenly lowered to low velocity gradients during flocculation, small flocs formed which neither grew nor settled during and after flocculation.

Coagulant feed concentration

- A coagulant feed concentration of 0,5 % has been suggested as optimal for good destabilization of particles (Kawamwa (1976), Griffith and Williams (1972). Too high a concentration for a given rapid mix device may result in poor water quality after flocculation and solid-liquid separation. However, too low coagulant solutions may result in poor performance due to pre-hydrolysis of metal species before addition to the raw water stream.

Polyelectrolytes

- Polyelectrolytes (normally cationic) can be used as coagulant aid (flocculant) to assist with coagulation and floc formation, but are not effective as primary coagulants on their own for treatment of coloured water.

- For polyelectrolytes, it is recommended that the feed concentrations are used according to suppliers' recommendations.

Coagulation treatment practices at plants surveyed

pH adjustment is accomplished by dosing lime (soda-ash is used by two of the smaller treatment plants) into the mixing race, either before or after the dosing of coagulant. The coagulant used by most of the treatment plants is aluminium sulphate (alum), while ferric sulphate is dosed at the Cape Town Municipality's Faure treatment plant and at Sandhoogte. The George new treatment plant and the Kleinbrak treatment plant have recently changed over to using ferric chloride as coagulant. None of the treatment plants surveyed use polyaluminium chloride for coagulation (PACℓ is used at treatment plants of the Port Elizabeth Municipality which treats waters with low colour concentrations - these plants were not amongst those that were surveyed). At most of the plants, the pH is adjusted to the optimum range for colour removal for the specific coagulant used (5,0 - 5,5 for alum; 4,0 - 5,0 for ferric sulphate; and 3,7 - 4,5 for ferric chloride). However, at some of the plants using alum, the pH is adjusted to 5,7 - 6,5 to minimize the aluminium residual in the final water.

At some of the Cape Town treatment plants, sodium aluminate is dosed in addition to alum to obtain more rapid floc formation and to reduce the treated water hardness (See Annexure F, paragraph 1.4).

At two of the plants, cationic polyelectrolytes are dosed in the flocculation channel to improve the settleability of the flocs, while bentonite and activated silica are dosed at two other plants for the same reason.

Control of coagulation process

Control of the coagulation process is, to a large extent, still done empirically by increasing the coagulant dosage when it becomes apparent that the colour removal efficiency is deteriorating, usually as a result of an increase in the colour of the raw water. When it is noticed (either by measurement or with the naked eye) that the raw water colour is decreasing again, the coagulant dosage is gradually reduced. At all the plants the coagulation pH is measured on a frequent basis and attempts made to maintain the pH at the optimum range prescribed by the plant manager; however, at a fair number of the plants the procedure for measuring the pH of these waters with low buffer capacity, and operation and maintenance of the pH measuring apparatus, is not consistent and gives rise to large fluctuations in the actual coagulation pH levels. This results in either poor colour removal, or overdosing of chemicals to achieve adequate colour removal. It was thus evident that there is a need for dosage curves whereby coagulant dosages can be adjusted more accurately according to actual measured raw water colour, and for standardisation of pH measurement and the use of pH meters.

b. Flocculation

Flocculation systems

Flocculation is generally accomplished by a gradual reduction in velocity gradient from the rapid mix unit to quiescent flow conditions in the sedimentation tank.

Flocculators may be:

- a single back-mix reactor (stirred tank)
- a number of stirred tanks in series
- a plug-flow reactor.

Bratby (1980) gives equations for the ratios of influent to effluent turbidities for the different types of flocculators. An examination of these equations shows that the improvement in water quality is dependent on:

- retention time
- velocity gradient (G)
- floc formation and breakup constants K_a and K_b.

Bratby also describes how to measure these flocculation constants in the laboratory.

The most frequently used flocculation systems in plants treating coloured water are baffled flocculation chambers (vertical plates) where the head loss through the chamber provides the mixing energy. A typical baffled channel is shown in Figure 6.3.

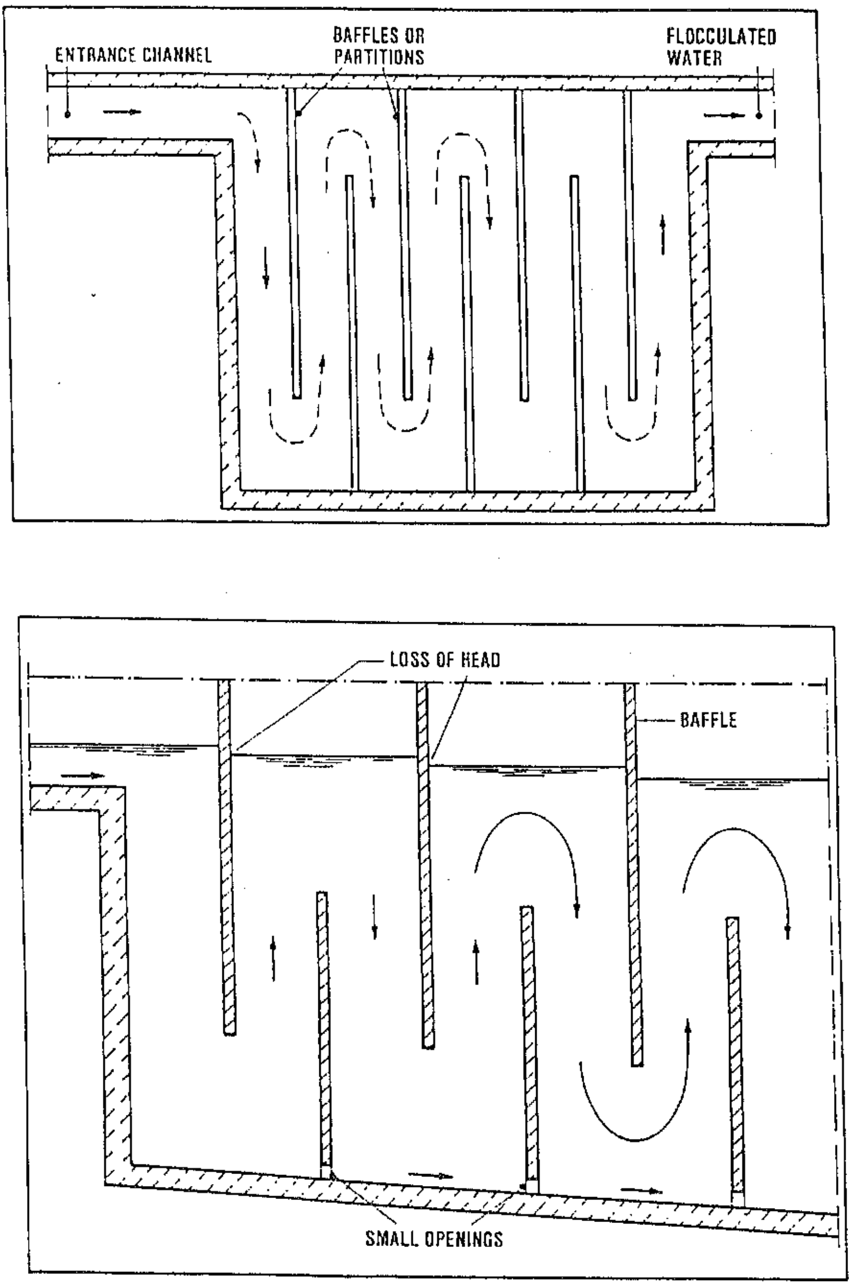


Figure 6.3 Baffled flocculation channels

In the treatment plants that were surveyed, flocculation takes place either in baffled chambers (vertical or horizontal baffles), or unstirred chambers.

Design aspects

In the design of a flocculator, not only the velocity gradient G should be taken into account, but also the retention time t. The product Gt gives a measure for the number of particle collisions, and thus for the floc formation action.

The formula for computing the velocity gradient is

$$G = (P/\mu V)^{1/2}$$

where G = velocity gradient (sec^{-1})
P = power transmitted to the water (kW)
V = volume of water to which the power is applied; where applicable, the volume of the flocculation basin
μ = kinematic viscosity of water (m^2/sec)

The recommended ranges of these flocculator design criteria are given below:

Design factor	G (s^{-1})	t (s)	Gt
Range	10 - 100	1 200 - 1 800	30 000 - 150 000
Typical value	45 - 90	1 800	50 000 - 100 000

For each individual flocculator, the optimal GT value should be carefully selected, and taken as high as is consistent with the optimal formation of flocs without causing disruption or disintegration of the flocs after they have formed. The internal cohesion of the flocs can be improved by chemicals such as activated silica or polyelectrolytes (see below).

Flocculation aids (coagulation aids)

Because of the lightness of the flocs that are formed in the coagulation of colour causing substances, flocculation aids are often dosed in the flocculation channel to give more weight to the flocs or increase their size, and thereby enhance removal. The flocculation aids that are most commonly used are:

- polyelectrolytes (mostly cationic)
- bentonite (weighting agent)
- activated silica

Flocculation aids that are dosed at treatment plants that were surveyed are given below, together with the reasons for their use:

Polyelectrolytes

High molecular weight cationic polyelectrolytes are sometimes dosed in low concentrations to improve the settling process and turbidity removal in general.

Polyelectrolytes are not dosed as primary coagulants on their own at any of the plants, because of their inefficiency for colour removal as mentioned earlier.

Bentonite

Bentonite is dosed at one plant after lime and coagulant to give weight to the flocs and improve settling.

Activated silica

Activated silica is used at one plant to improve the performance of a sludge blanket settling tank. (For more information, see Appendix F).

6.1.2 PHASE SEPARATION

a. Settling

Types of settling

The following types of settling tanks are used in colour removal treatment plants:

- horizontal settling tanks
- circular settling tanks

At all but one of the treatment plants horizontal settling tanks are used for sedimentation. A variety of designs have been used, especially on the inlet and outlet arrangements, with varying degrees of success. At a number of the treatment plants, the settling tanks have been covered with asbestos sheets or shade nets (see *Effect of temperature and wind on settling* below).

Dimensions of horizontal settling tanks

It has been found that long horizontal settling tanks (*i.e.* with length considerably greater than the width) produce better removal of colour flocs than the more square type horizontal settling tanks for the same residence time in the tanks. The horizontal settling tanks used at the Blackheath and Faure treatment plants have been shown to be near optimal in efficiency for coloured floc removal and producing a high quality settled water.

Settling rates and retention time

The Cape Town Municipality bases the design of their settling tanks on years of experience and design evolution at the Council's plants. It considers the design of the Blackheath settling tanks as the best for the treatment of coloured waters.

At the Constantia Nek treatment plant two types of settlement are used: the first is an upflow sludge blanket clarifier and the other is a high-rate inclined-tube settler. The upflow sludge blanket clarifier receives about one third of the flow through the plant, which gives a settling rate of 1,2 m/h. This gives a very good quality water when the flow is low enough, but the quality of the overflow deteriorates drastically when higher flows are encountered. The inclined-tube settler receives the remaining two-thirds of the flow through the plant, and operates at a settling rate of 3,3 m/h. It does not produce as good a quality of settled water as the upflow sludge blanket, but produces a more consistent quality, and performs better at high flows.

Inlet and outlet arrangements of horizontal settling tanks

For optimum sedimentation tank performance, it is essential to ensure even flow distribution across the cross-section of the tank. The weak nature of the coloured water floc requires that particular care be taken in the transition from the flocculator to the settling tank. This requirement generally precludes the use of inlet control as depicted in Figure 6.4 (a), where the head loss H at the inlet to the tank is likely to result in floc breakup. The most effective settling tanks are those which employ outlet control or which complete the final stage of flocculation within the settling tank itself (Figure 6.4 (b))(Reid, 1986).

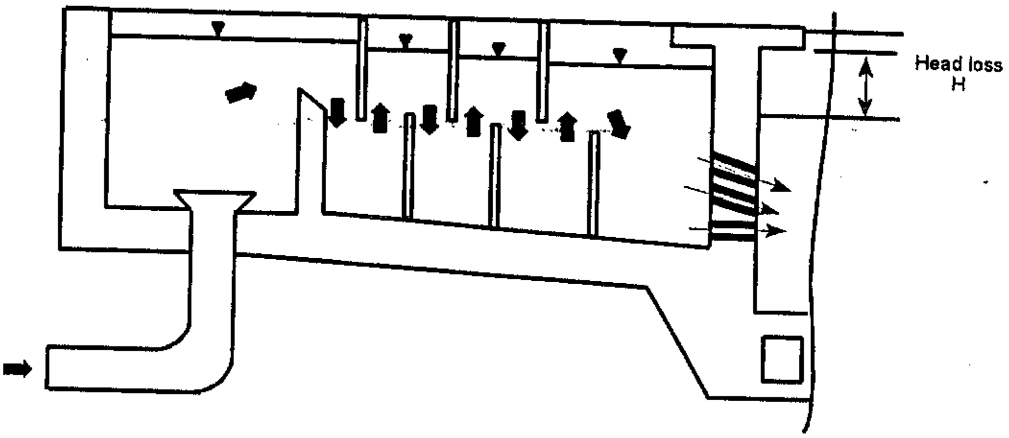


Figure 6.4 (a) Baffled flocculation chamber with inlet control to settling tank

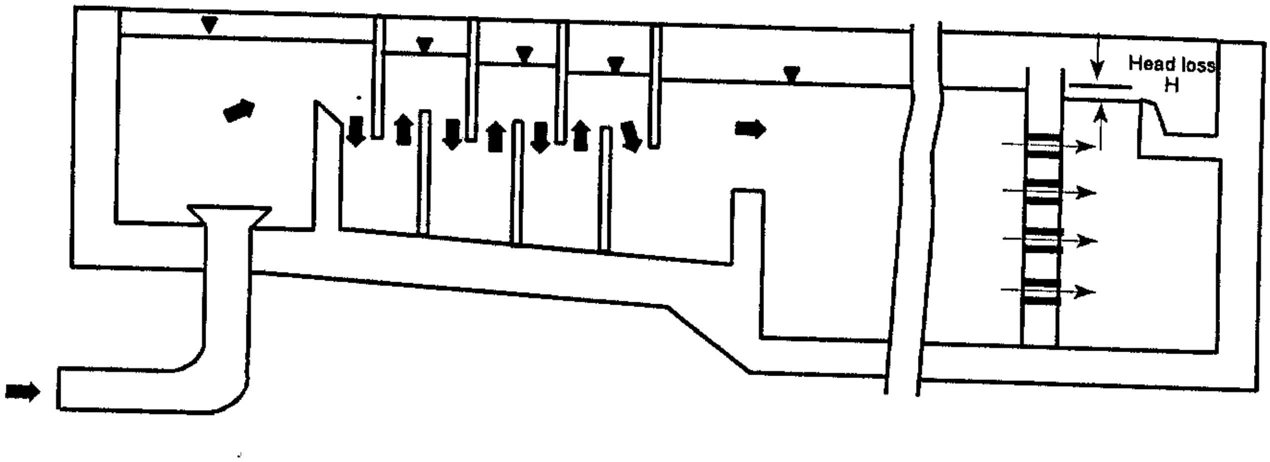


Figure 6.4 (b) Baffled flocculation chamber with outlet control from settling tank

Effect of temperature and wind on settling

According to plant operators or supervisors at most of the plants visited, elevated water temperatures in the upper zones of the settling tanks caused by direct sunlight on the water surface tend to lift the light flocs and result in floc carry-over from the settlers.

To prevent this from taking place, a number of plants have covered their settling tanks with asbestos roofs. This also prevents strong wind from causing turbulence in the settling tanks which results in floc carry-over. There is also a tendency to use black shade net rather than asbestos plates for safety reasons, while it is also more aesthetical and requires less maintenance. In the experience of the Cape Town Municipality, however, sheeting is better to use because the wind constantly tears shade nets.

One of the more recently constructed plants in the study area (at George) has been built inside a building, thereby preventing any problems with temperature changes due to direct sunlight on the settling tanks surface, or to the effects of strong winds. The same plant does, however, experience problems from time to time with raw water entering the plant at different temperatures and causing turbulence and floc rise in the settling tanks.

Materials of construction

At most of the Cape Town Municipality's water treatment plants treating water with low pH values, the concrete surfaces of the settling tanks are protected with a bitumen coating.

b. Dissolved air flotation (DAF)

In a pilot-scale study on coloured waters by Edzwald and Malley, Jr. (1990), it was found that the optimum coagulation conditions for DAF (*i.e.* particle destabilization; particle-bubble attachment) are the same as for sedimentation (particle destabilization; particle-particle attachment). The implication of this is that jar tests can also be used to select optimum coagulation dosages for the DAF process.

Their study showed that flotation performance depends on raw water quality, pretreatment (coagulation and flocculation), bubble size and bubble volume concentration. DAF is effective in treating water supplies containing humic substances or natural colour (DOC concentrations as high as 12 mg/ℓ with true colour values of nearly 200 Pt-Co colour units were tested). They also found that long flocculation times are not necessary, and that pin-point sized flocs of 10 to 50 μm should be introduced into the DAF unit.

Comparison of DAF with conventional gravity settling indicated comparable removals of DOC, UV, true colour, and dissolved organic halide precursors (TTHMFP, TOXFP). These findings support the premise that removal of dissolved contaminants is independent of the solid/liquid separation process used. Comparable levels of residual dissolved aluminium were also found after DAF and conventional gravity settling.

DAF produced lower turbidities than sedimentation when treating coloured water containing turbidity.

An 8 % recycle ratio was found to be sufficient for good colour removal with DAF.

In a study by Arora *et al* (1995), dissolved air flotation was evaluated for water clarification and sludge thickening. A DAF pilot study was conducted on one water source with low turbidity, high colour, high organic content and algal blooms. For this water, coagulation with alum, cationic polymer and pH around 6,1 resulted in removal of turbidity, colour and algae. THMFP and TOC were removed by approximately 25 and 50 percent, respectively.

A river water source was used in another pilot study (Arora *et al*, 1995) to identify limits on raw water turbidity for the DAF process. Tests conducted with induced high turbidity values resulted in filtered water quality with low turbidity and complete removal of colour. TOC was removed by approximately 35 percent; however, inconclusive results were obtained for THMFP removal. Based on these pilot tests, according to the researchers DAF is a viable clarification process, especially for source waters with low turbidity, high algal blooms and high colour.

Pilot-scale tests for evaluation of DAF in treating Cape coloured waters

- Sandhoogte

Pilot-scale tests were done at Sandhoogte using a 450 ℓ/h DAF pilot plant. The following were investigated: coagulant dosage requirements for effective colour removal, and effect of the quantity of air.

Two coagulants were used, namely alum and PACℓ, and recycle ratios were varied between 5 and 15 % of the total flow (saturator pressure was 400 kPa). For every run the turbidity and colour of the subnatant were determined after stable flow conditions were achieved.

The colour levels were reduced from around 400 - 600 mg/ℓ as Pt down to 20 - 30 mg/ℓ as Pt. Colour levels of less than 20 mg/ℓ could not be obtained, even at recycle ratios of 15 %. At 5 % recycle ratio reasonably good colour removal was already obtained, with higher recycle ratios resulting in only slight improvement of colour removal. Good flocculation was found to be a prerequisite for good removal of both colour and turbidity, with poor results having being obtained at non-optimum coagulation conditions. The same coagulant dosages were required as for settling in coagulation beaker tests. More detailed evaluation of the DAF process for colour removal was not undertaken during these trials (*e.g.* evaluation of upflow and downflow velocities; effect of sludge float layer; bubble concentrations, etc.).

- Plettenberg Bay

A pilot plant study was also done by consulting engineers at the Plettenberg Bay water treatment plant using a versatile 1 m^3/h SEDIDAF pilot plant built by Watertek, CSIR (Lombard, 1994).

The SEDIDAF plant consists of the following unit processes combined into an integrated water treatment unit:

- an adjustable, baffled, plug-flow flocculation chamber, with in-line mixers for coagulant dosing and pH adjustment ahead of the flocculation unit
- a countercurrent inclined-plate sedimentation unit
- an integrated dissolved-air flotation/filtration unit. The unit uses the NIWR nozzles that are designed for the formation of microscopic air bubbles
- a sludge thickening grid at the surface of the flotation cell.

Test runs were performed with the pilot plant using alum as primary coagulant and three different polyelectrolytes as coagulant aids. Recycle ratios in the DAF process were varied from 10 to 25 % and saturator pressure from 300 to 500 kPa. It was found that good colour removal could be obtained (from 150 mg/ℓ Pt to less than 5 mg/ℓ Pt) at 40 mg/ℓ alum and 0,5 mg/ℓ cationic polyelectrolyte dosage, but that instability of the float layer that was formed resulted in settling of the flocs out of the float layer into the bottom of the clarification zone, causing high colour values in the treated water. Thus, although good colour removal was possible at times, consistent quality control could not be maintained because of the unstable sludge layer. Further research is required to stabilize the sludge float on the surface of the clarification zone to prevent flocs settling to the bottom, and thereby ensuring consistent plant performance.

Although no full-scale DAF treatment plants have been built for the treatment of coloured waters in the Cape, a package plant using DAF technology has been installed and is operating at the Saasveld College near George.

c. Filtration

Rapid sand filtration

The following types of rapid sand filtration are used in water treatment:

Declining rate filters

In declining rate filters, the rate of flow through each filter declines as the filter cycle proceeds. Immediately after backwashing the rate of flow is the highest. As impurities collect in the media, the filter head loss increases. When the rate of flow declines to a predetermined level the filter is backwashed. These filters do not require expensive equipment to control the rate of flow through each filter. Reid (1996) states that overseas experience shows the following:

- the effluent quality is superior to that of constant rate filters
- declining rate filters can only be used where a minimum of 4 filters are required
- the cost of mechanical plant is lower than for constant rate filters
- civil construction costs are of the same order as for constant rate filters.

Constant rate filters

The rate of flow through each filter is controlled so that each filter receives the same flow. This is achieved by either splitting the flow over a weir at the inlet to each filter (essential where rising head filters are used), or by means of downstream control to maintain a constant water level above the filter (constant head filter).

- Rising head filters
  Splitting of the inflow over a weir, as required for rising head filters, causes breakup of residual floc. The effluent from these filters is generally inferior to that from constant head filters, and for this reason rising head filters are not favoured.

- Constant head filters

  Constant head filters with downstream control are the most commonly used filters in South Africa (Reid, 1996). With these filters, submerged inlets that have only a small head loss and cause minimum floc breakup can be used. A sudden increase in the flowrate through the filter will cause a decline in effluent quality. The sensitivity and accuracy of the flow control system is therefore of paramount importance. It is important that the designer clearly specify his requirements and check that these are met by the system that is selected.

Rapid sand filters are used in most of the plants surveyed in this study. One treatment plant uses slow sand filters in combination with pressure sand filters, while another has converted slow sand filters to secondary settling tanks, and was using no filtration at all. A single grading of sand is used in most instances as filter medium. Backwashing of the filters appears to be based on experience rather than following actual guidelines, both in terms of method and duration of backwashing. At most of the plants backwashing is done once a day on routine basis because of the ease of control, and to ensure that colour breakthrough does not take place. The higher cost of energy and water consumption when backwashing in this way appears to be offset by the better control that it offers. This is further justified by plants that recycle their backwash water, or generate their own electricity for use in the treatment works (Cape Town). At the larger plants with many sand filters, routine backwashing is also said to prevent possible congestion when more than one filter may have to be backwashed at the same time.

Length of filter runs

Cape Town Municipality backwashes their filters daily to make sure they are clean and excessive head-loss development or floc breakthrough does not take place. Backwashing frequency can be optimised, but a fair margin of safety should be allowed for.

It is not possible to backwash all the filters at the same time. At many plants, especially the larger plants, it is therefore essential that backwashing is rather done on a routine basis to prevent congestion.

Filter underdrain systems

The underdrain system consists of a number of nozzles spaced evenly over the floor of the filter to collect the filtered water and distribute the backwash water and air scour evenly over the full floor area. The nozzles are either fitted to pipe laterals or into a false floor. The selection of the type of underdrain system depends to some extent on the backwash system selected. Where a false floor is selected, it is important to provide access beneath the floor to facilitate the removal of any filter media that may pass through the nozzles. Where a pipe lateral system is used, the removal of such media is almost impossible.

The size of the slots in the filter nozzles dictates the configuration of the filter media. If a fine slotted nozzle is used, the slots must be smaller than the filter media. In this case the filter media are placed directly over the nozzles. Where the nozzle slots are coarser than the filter media, support layers are required that will prevent filter media passing into the collection system. The choice of nozzle is also influenced by the backwash system selected.

In an investigation by Lempert, van Leeuwen and Pretorius (1992) to compare different filter underdrain systems at the old George water treatment plant, it was found that the best type of filter for removing the flocs as obtained at the George purification plant (*i.e.* coloured water flocs) was one with a single, homogeneous layer of sand with an underdrain system consisting of a false filter floor with nozzles.

Many problems were experienced with the filters consisting of a stratified sand bed with pipe lateral underdrain system. These filters were not suitable for removing the flocs as obtained with the particular water found at George and Plettenberg Bay and gave many operational difficulties. Washwater consumption of this filter was also high with 4,2% of the total amount of filtered water used for backwashing.

The best filter underdrain system for flocculated coloured water is therefore the following (as confirmed by testwork done at George):

- a false filter floor with nozzles
- a single, homogeneous layer of sand
- an unstratified sand bed
- backwashing with simultaneous air scour and filtered water

Backwashing procedures

Filters can be washed by means of:

- a reverse flow of water only
- a reverse flow of air (air scour) followed by a reverse flow of water
- air scour, followed by a reverse flow of air and water, and a final water wash.

The first system is seldom used anymore in South Africa (Reid, 1996). The latter two systems are the most common. In selecting the most suitable system for a treatment plant, the following considerations should be borne in mind:

Air scour followed by a reverse flow of water

- This system can be used with either type of underdrain system or size of nozzle slot.

- Where coarse slotted nozzles and media support layers are used, care must be taken to ensure that the support layers are not disturbed at the onset of air scour. This can be accomplished by initiating the air scour at a reduced rate, until all the water has been expelled from the nozzle/underdrain system. After air scour and before starting the wash water, sufficient time must be allowed for all the air to escape from the nozzle/underdrain system.

Air scour followed by a reverse flow of water and air

- This system is not applicable where coarse slotted nozzles and filter media support layers are used, as the support layers will be disturbed by the combined air-water scour.

- This system should only be used with a false floor system and not with a pipe lateral system.

To be most efficient, the sand bed should not be stratified during backwashing. This can be done with simultaneous water and air backwashing.

Direct filtration

Direct filtration is a treatment process where all of the particulates or flocs are removed in the filters; there is no sedimentation tank. Two methods are used: (1) in-line filtration, sometimes called contact-filtration, and (2) direct filtration with a flocculation tank prior to the filters. Direct filtration is an attractive alternative to conventional water treatment with best application to the treatment of high quality, low turbidity supplies.

Good removal of colour from natural coloured waters by direct filtration has been reported by Glaser and Edzwald (1979), who used a series of polyethylenimine polymers with molecular weights ranging from 600 to 50 000 - 100 000, and by Scheuch and Edzwald (1981), who used a chlorine-resistant cationic polymer (polyquaternary amine) of approximately 50 000 molecular weight. In both studies, a bench-scale pilot filter having a 140 mm filter bed (mean grain diameter 0,6 mm) was used, and tests were performed at pH 5,5 - 6,0. Stoichiometry between initial humic concentration and optimal polymer dosage was observed for both destabilization and filtration.

Edzwald *et al* (1987) investigated the effects of raw water quality, pH, coagulant type and dosage, as well as some physical filtration variables (filtration rate, flocculation period, and temperature) on the performance of direct filtration. The work employed a large-scale pilot dual-media filter and two natural coloured waters. For comparison, alum and three cationic polyelectrolytes (polyquaternary amine) were included as coagulants. The three polymers were effective in treating both waters by direct filtration. Although optimal polymer dosages varied from one polymer to another, the actual positive charge added was very similar for all polymers and agreed well with the estimated amount of negative charge associated with the organic matter in the raw water.

On the basis of the results of these and previous studies, Edzwald *et al* suggested that the use of direct filtration with cationic polymers as the sole coagulant would be limited to raw waters with low to moderate TOC values (less than 5 mg/ℓ), and hence low to moderate organic colour in the water. Thus, for waters with higher TOC levels, the polymer dosages would be too high and costly, and the quality of the treated water would not be satisfactory in terms of TOC and trihalomethane (THM) precursors. They found higher removals of TOC and THM precursors with alum than with any of the three polymers. However, these authors do not recommend the use of alum in direct filtration of waters with high TOC concentrations (high colour) because very high alum dosages would be required and, even under well-controlled pH, precipitation of aluminum hydroxide could occur, leading to short filter runs.

The use of direct filtration preceded by alum coagulation at low pH values to remove humic substances from Norwegian lake sources has been investigated by Fettig *et al* (1988). Although colour removal up to 90 percent was obtained in preliminary jar tests (0,45-μm membrane filtration) at an optimal pH between 5,5 and 5,9, floc separation in that pH range, by either direct filtration or sedimentation, was not efficient. Floc filterability was shown to be good at pH 4,75 but deteriorated dramatically between pH 5 and 6, improving again at pH values above 6,0. The changes in floc filterability were attributed by the authors to changes in the chemical structure of the floc. Because at low pH (< 5) the ultimate removal of colour was not enough to achieve acceptable levels of colour in the filtered water, the authors suggested that the technical application of direct filtration at low pH should also involve stabilization of the water followed by a second filtration stage (at pH > 6).

In the United Kingdom, there is great reluctance by operators to employ alum at pH values < 6 in single-stage direct filtration because of possible problems with residual aluminum (Britton and Cochrane, 1989). Consequently, at times of high colour loadings, the correspondingly high alum dosages (> 20 mg/ℓ) produce significant quantities of insoluble hydroxide floc.

In a study to investigate the applicability of using direct filtration for colour removal form Cape coloured waters, Brown (1987) performed tests with a pilot scale filtration unit at the Maraisdal water treatment plant near Caledon. Alum was used as coagulant with pH adjustment, and trials were done using a filter sand with 0,6 mm effective diameter for the first trial and effective diameters of 0,65 to 0,92 mm for subsequent trials. For raw colour levels of up to 80 mg/ℓ as Pt, filter runs of more that 35 hours were possible to give a filtrate of less than 5 mg/ℓ Pt; however, at higher colour levels more rapid colour breakthrough and/or reaching of maximum head loss occured, resulting in only short filter runs being possible. Although it was suggested that further studies would be necessary to evaluate design parameters for application of direct filtration for treatment of Cape coloured waters, the general conclusion drawn from the study was that direct filtration would only be suitable for treatment of coloured waters with colour levels of less than 80 - 100 mg/ℓ as Pt.

Direct series filtration

Tests with a direct series filtration pilot plant were performed at Sandhoogte.

Series filtration is a two-stage filtration process consisting of either an upflow or downflow filter as contact clarifier in the first stage, followed by a rapid gravity downflow filter as the second stage.

Raw water was pumped from the inlet works of the Sandhoogte full-scale plant to the pilot plant. Lime was dosed to the raw water for pH adjustment and, some distance further, alum was dosed as coagulant. The lay-out of the pilot plant set-up is shown in Figure 6.5.

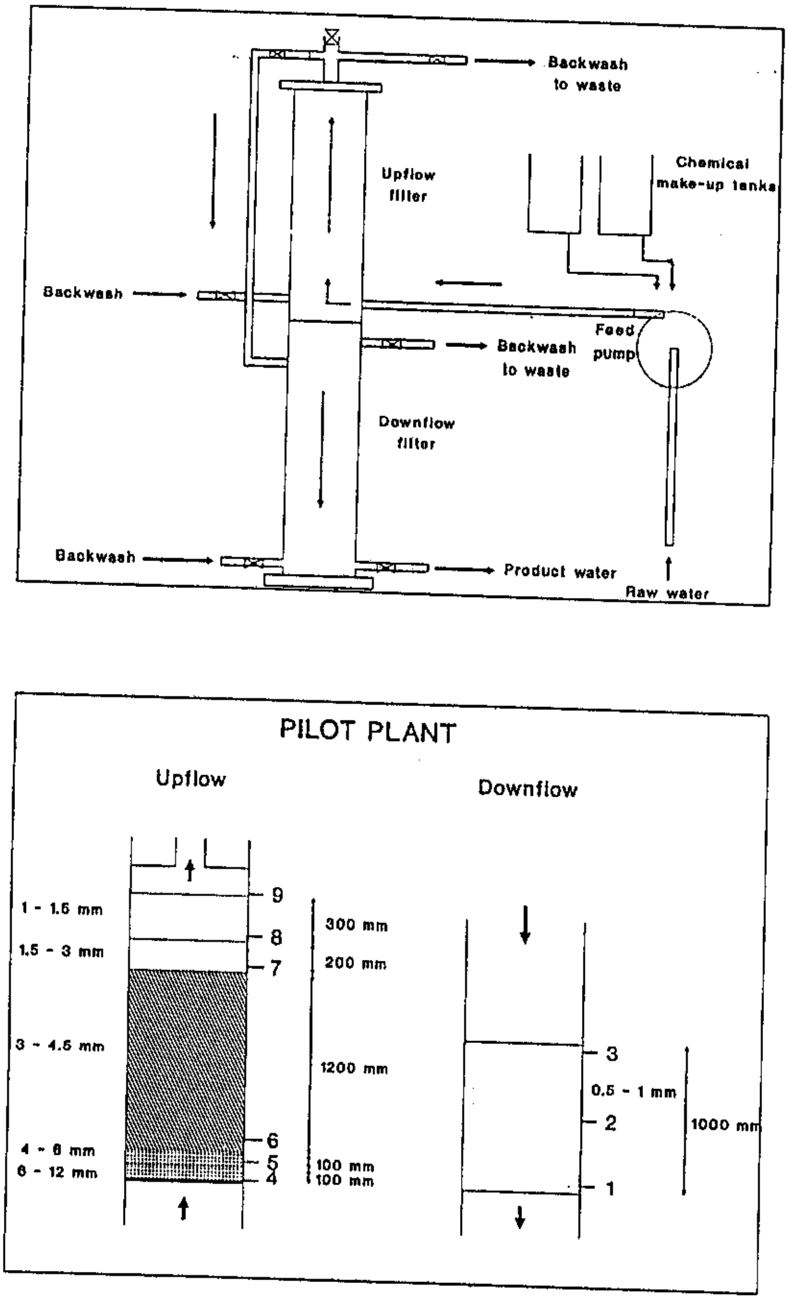


Figure 6.5 Schematic of direct series filtration pilot plant

The optimum alum dosage and pH for good flocculation was determined in beaker tests at the start of each new filter run. The lime dosage on the pilot plant was adjusted to give the optimum pH that was determined for that filter run's raw water feed. The optimum alum dosage was 100 mg/ℓ and the optimum pH in the range 4,7 to 5,2.

Test runs were done at filtration rates of 5,10 and 20 m/h. The runs were terminated when colour breakthrough or excessive head loss development occurred. Samples taken were analysed for pH, apparent colour, true colour, turbidity and aluminium.

Main results are summarized in Table 6.2.

Table 6.2 Direct series filtration pilot-scale tests at Sandhoogte, Mossel Bay

Filtration rate (m/h)	Coagulant/ coagulant aid	Dosage (mg/ℓ)	Colour removal (%)	Filter run time (h)	Mean filtered water colour (mg/ℓ Pt)
5	Alum	100	87 - 97	21	32
10	Alum	100	71 - 98	10,5	64
20	Alum	100	52 - 74	3,5	122
5	Alum LT 22	140 1,0	82 - 96	15	61
10	Alum LT 22	140 1,0	74 - 91	9,5	109
20	Alum LT 22	140 1,0	-	2,5	62

Colour removal with the direct series filtration system was erratic, with reasonable colour removal being achieved at times, but with breakthrough of humic flocs and resulting poor final water quality occuring during early stages of most of the filter runs. Penetration and resultant shear of the flocs in the filter media appears to take place after some time during the filter runs, even at low filtration rates. This can be ascribed to the fragile nature of the humic flocs that are formed during coagulation of the coloured water.

The apparent colour of the product water after the downflow filtration stage varied between 16 and 65 mg/ℓ as Pt for the 5 m/h filter run, and between 9 and 154 mg/ℓ as Pt during the 10 m/h run. The shear force during the higher filtration rates resulted in floc breakup in the downflow filter, with resulting colour breakthrough. In most of the cases, the colour levels obtained after upflow filtration were lower than that of the final water, which indicate that the downflow filter could not achieve good floc removal on a consistent basis, even at the low filtration rate.

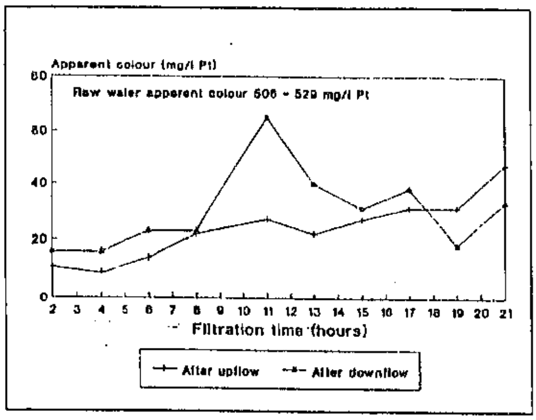
The run times of the filter were 20 hours for the 5 m/h filter run, 10,5 hours for the 10 m/h run and 3,5 hours for the 20 m/h run, before the maximum pressure drop accross the filter was reached. High turbidities were measured in the water after the upflow filtration stage, which was subsequently reduced by the downflow filter to values of 1 to 15 NTU, showing the inefficiency of the downflow filter to produce a high quality water under these conditions.

The use of a cationic polyelectrolyte together with alum did not result in the expected improvement of the quality of the product water by providing more "strength" to the floc. The filter run times were also of similar duration as when only alum was used.

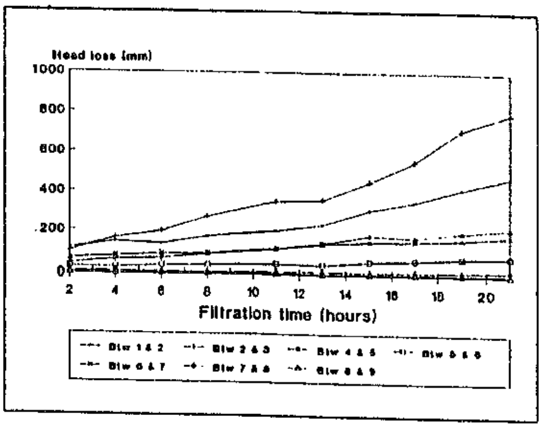
Results of the tests are shown graphically in Figure 6.6.

Slow sand filtration

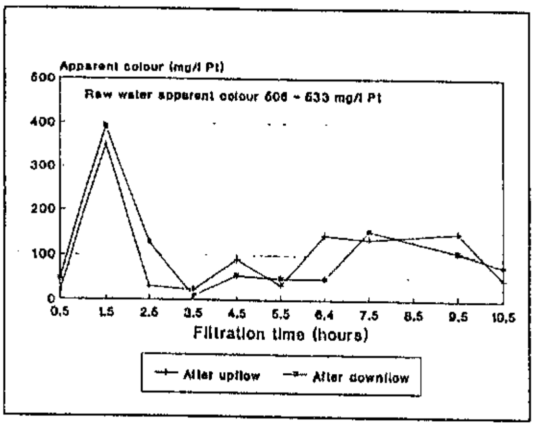
Conventional slow sand filters have only a limited capacity for removing the non-specific dissolved organic compounds that comprise the organic carbon and organic colour components of potable raw waters, and are observed generally to not be as effective as conventional rapid sand filtration processes.



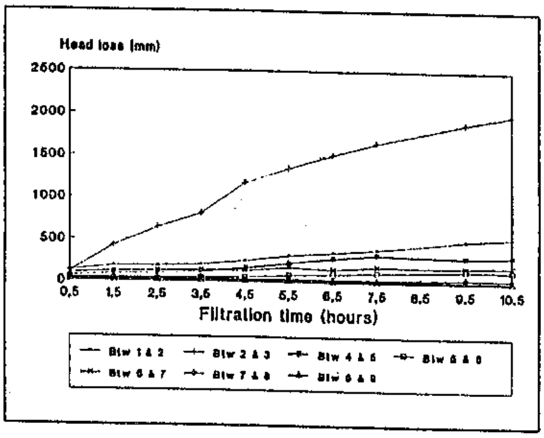
Filtration rate 5 m/h and 100 mg/ℓ alum



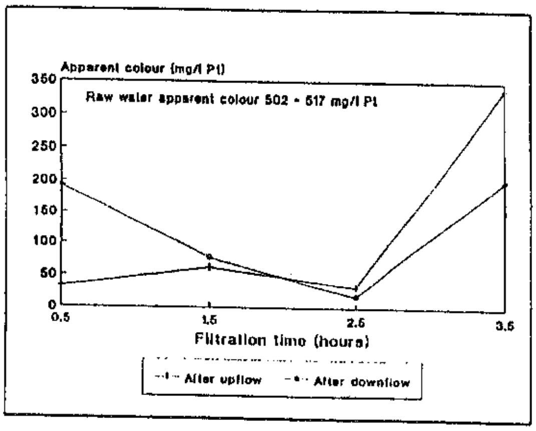
Filtration rate 5 m/h and 100 mg/ℓ alum



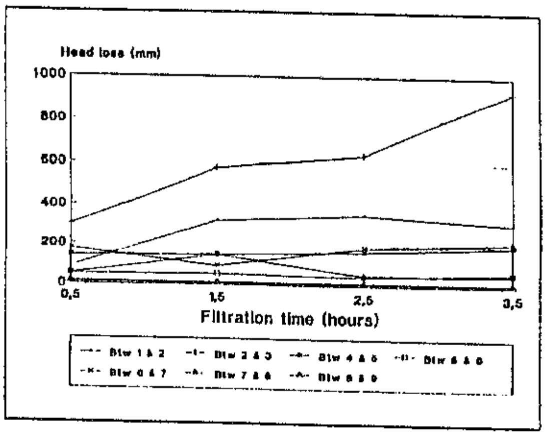
Filtration rate 10 m/h and 100 mg/ℓ alum



Filtration rate 10 m/h and 100 mg/ℓ alum

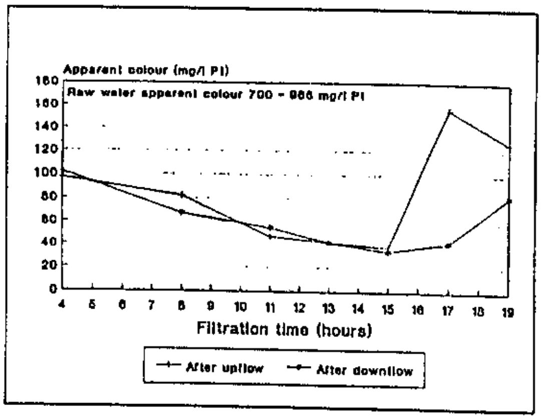


Filtration rate 20 m/h and 100 mg/ℓ alum

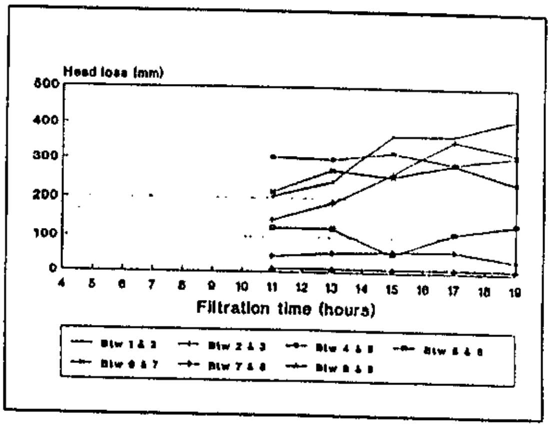


Filtration rate 20 m/h and 100 mg/ℓ alum

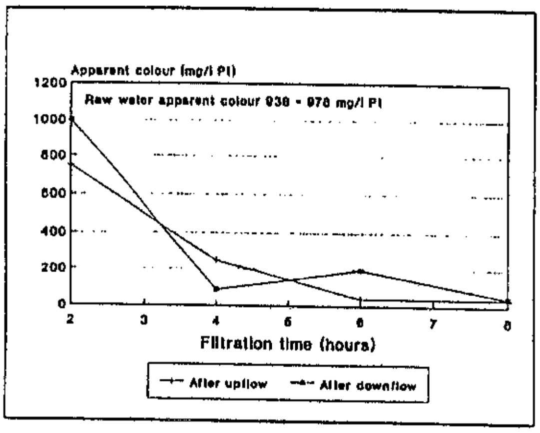
Figure 6.6 (a) Colour removal with the direct series filtration process (alum only)



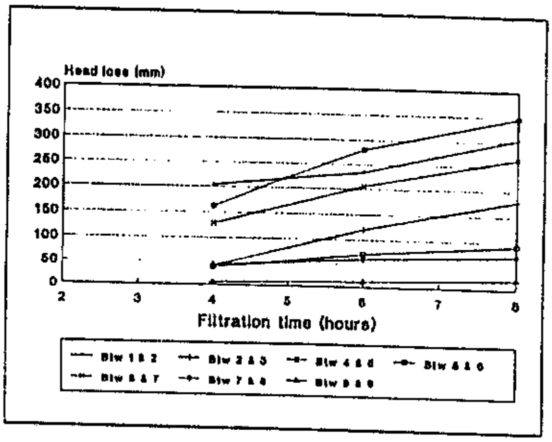
Filtration rate 5 m/h, 140 mg/ℓ alum and 1,0 mg/ℓ LT 22



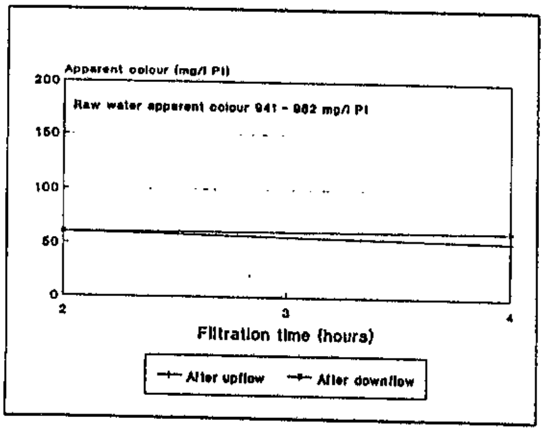
Filtration rate 5 m/h, 140 mg/ℓ alum and 1,0 mg/ℓ LT 22



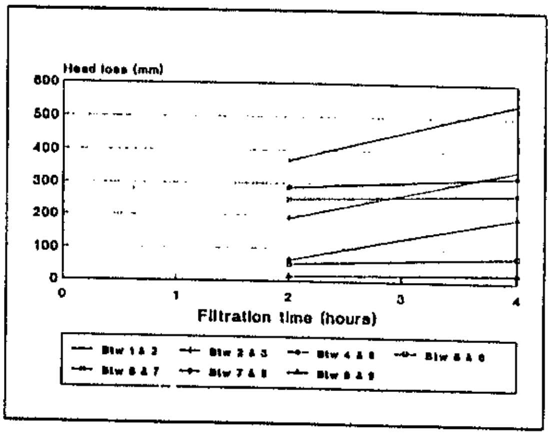
Filtration rate 10 m/h, 140 mg/ℓ alum and 1,0 mg/ℓ LT 22



Filtration rate 10 m/h, 140 mg/ℓ alum and 1,0 mg/ℓ LT 22



Filtration rate 20 m/h, 140 mg/ℓ alum and 1,0 mg/ℓ LT 22



Filtration rate 20 m/h, 140 mg/ℓ alum and 1,0 mg/ℓ LT 22

Figure 6.6 (b) Colour removal with the direct series filtration process (alum plus polyelectrolyte)

There appears to be a large difference in colour removals achieved by slow sand filters treating water sources. For all water sources, reported colour removals ranged in the literature from between 15 and 80%, with a mean removal of 34% (Lambert and Graham, 1989). It was established that apparent differences in organics removals due to the influent organics concentration or filtration rate were statistically insignificant. Similarly, the extent of pre-treatment applied to raw water prior to a slow sand filter appears, generally, to be insignificant to the percentage organics removal achieved.

6.1.3 MEMBRANE PROCESSES

Membrane filtration is receiving increasing attention as a technology for the removal of natural organic matter (NOM), particularly with tighter control of disinfection by-products (DBPs). Although membrane filtration is not yet a widely accepted treatment technology for colour removal, recent cost estimates suggest that it may be competitive with conventional treatment for plants with capacities of less than 20 Mℓ/day (Nilson and DiGiano, 1996). This competitive edge may shift more in favour of membrane processes if simple modifications to conventional treatment (*e.g.* enhanced coagulation) are not sufficient to meet the new regulations in overseas countries. However, optimization of membrane technology requires still greater understanding of separation science, especially the concepts that explain rejection of NOM and fouling by NOM.

Estimates of NOM rejection are usually based on the rated molecular weight cutoff (MWCO) of a membrane. For instance, studies have shown that more than 90 % rejection can be achieved using membranes with MWCOs of 200 - 300 daltons. However, rejection of solutes can be influenced by factors other than size, such as charge and polarity. A review of reverse osmosis (RO) research shows that the rejection of low-molecular-weight polar organics generally decreases with increased polarity of the membrane material, though rejection of high-molecular-weight or nonpolar organics is less dependent on the membrane material. The influence of size and charge characteristics of NOM and physicochemical interactions between the membrane and NOM (*e.g.* electrostatic repulsion of highly charged NOM by a charged membrane surface) should also influence rejection, but these effects have been less well studied.

Many factors contribute to the decline in permeate production over time that is often observed in nanofiltration (NF). The most significant of these factors are fouling from solute adsorption, solute and particulate adsorption, pore blockage and plugging, and membrane compaction. The amount of permeate flux recovered by the hydrodynamic cleaning is due to removal of rejected solute and particulates that physically accumulate on the membrane surface. Flux that is recovered by chemical cleaning is attributable to removal of rejected material that is physically or chemically sorbed on the membrane. Flux decline influences the operating and capital cost of membranes in two ways: first, it determines the frequency with which membranes must be rinsed, cleaned or both to remove accumulated materials, and second, it possibly determines the frequency of membrane replacement if irreversible fouling is significant.

NOM in surface waters has been implicated as a cause of flux decline. Some fractions are removed by hydrodynamic cleaning, others by chemical cleaning, and still others may be irreversibly bound to the membrane surface. The extent of interactions between NOM and the membrane surface may also be influenced by the nature of the membrane surface; for instance, in one study, greater fouling was found using hydrophobic membranes than with hydrophillic membranes.

In an investigation by Juby and Botha (1994) into the removal of colour from the Southern Cape waters by ozonation and membrane processes, the following conclusions were reached:

- the investigations indicated that nanofiltration membranes are superior to ultrafiltration membranes for the removal of natural colour from Cape waters

- the nanofiltration membranes chosen for the pilot plant investigation were able to achieve better colour removal efficiencies than ozonation, the best two membranes producing product water with colour values of less than 5 mg/ℓ as Pt from a water having a colour of 300 mg/ℓ Pt

- nanofiltration is a technically viable option for colour removal of humic/fulvic type waters at the 80 % recovery levels, but even higher recoveries may be possible

- membrane fouling was a problem. The foulants did not appear to be bound irreversibly to the membrane and cleaning was effective. The reason for the fouling was probably mainly the relatively high turbidity of the feed water to the pilot unit.

  According to the investigators, there can be no question about the practicability of pretreatment to remove the fouling but this needs to be a very inexpensive process, in order to ensure the economic viability of the membrane colour removal process.

- they state that preliminary indications are that the cost of nanofiltration membrane separation of colour could be about 55 % above the cost of conventional metal salt coagulation treatment processes.

More recently a pilot scale ultrafiltration unit was tested at Suurbrak in the South Western Cape (Jacobs *et al,* 1996). The capillary membranes employed in the test plant were of the outer-skinless polysulphone type, typically with an outer diameter of 1,8 mm and an inner diameter of 1,2 mm.

The unit was able to reduce colour in the raw water from around 350 mg/ℓ as Pt to less than 10 during some of the runs. In most, instances, the colour in the final product water was less than 50 mg/ℓ Pt. Further tests on a module that was cleaned thoroughly showed that if the membranes are in a good condition filtrate colour levels of less than 20 mg/ℓ can be maintained (a cleaning solution containing an alkali, detergent and sequestrant proved to be very effective). However, once damaged membranes are present (> 1000 h) the colour retention capability of the modules deteriorates markedly. Future work would concentrate on techniques to increase the specific flux of the membranes. This work would involve an investigation into the introduction of flow-destabilising operating protocol by which the deposition of foulants on the membrane surface could be retarded. Different membrane materials and module designs will also be investigated to improve the overall filtration productivity and plant performance.

6.1.4 OXIDATION PROCESSES

a. Ozone

Ozone, a strong oxidant, is capable of breaking down complex humic acids into simple (short-chain) acids and, in doing so, removes many of the colour progenitors from the water. However, unless prolonged and extensive ozonation is practised, simple short-chain breakdown products will persist. It would be preferable to remove these reaction products from the water prior to postchlorination for disinfection. This can be achieved by following the ozonation step with adsorption on activated carbon, or filtration through a biologically active carbon bed or sand filter.

In a pilot-scale study funded by the WRC and carried out by Stewart Scott Inc. and Watertek (Stellenbosch) to investigate the removal of colour from Southern Cape coloured waters (Juby and Botha, 1994), ozonation tests were done with a pilot-scale ozonator.

Initial calculations of the cost of an installation to reduce colour using ozone at a reacted dosage of 70 mg/ℓ indicated that this process would be considerably more costly than the conventional alum coagulation method. However, if the ozone dosage could be reduced to approximately 20 mg/ℓ and followed by biologically active GAC or sand filtration, then the process economics became more favourable.

b. Ozone in combination with hydrogen peroxide and/or UV radiation

In another WRC project, bench-scale tests were done by Watertek to investigate the reduction of colour by chemical oxidation (Van der Walt, 1995). The water used in the tests was spiked with humic acid and filtered to produce a water with a colour value of 300 mg/ℓ as Pt.

Ozone alone

The spiked water was ozonated at different pH levels to determine the effect of pH on colour reduction. It was found that better colour reduction took place at the higher pH value of 10 and at a neutral pH, than at an acidic pH value. There was almost no difference in colour reduction at pH 10 and at pH 7.

Peroxone

The effect of peroxone (ozone in combination with hydrogen peroxide) on the reduction of colour was investigated at a neutral pH with an H_2O_2/O_3 ratio of 0,4. The recommended limit for colour in potable water of 20 mg/ℓ as Pt was reached with an ozone dosage of 12,5 mg/ℓ, whereas for peroxone, the ozone dosage needed to achieve the same amount of colour reduction was 8,75 mg/ℓ. The effect of different ratios of H_2O_2/O_3 was also investigated and it was found that colour reduction took place more rapidly at a ratio of 0,3 and higher.

Ozone/UV

Ozonation under UV light performed very much the same way as peroxone.

Hydrogen peroxide

Colour reduction by H_2O_2 alone was also investigated at different pH values and dosages. Colour reduction was not as effective as with peroxone or normal ozonation and could only attain a level of 120 mg/ℓ as Pt.

Chlorine

The oxidation of humic substances by chlorine was partly successful, where removal of 56% of the colour was obtained. In this case oxidation was more efficient at lower pH levels.

Chlorine dioxide

Oxidation by chlorine dioxide ($C\ell O_2$) reduced the colour in the water down to a level of 121 mg/ℓ as Pt, also at the fairly high dosage of 15 mg/ℓ. The reduction was equivalent at acidic and alkaline conditions.

UV

Oxidation of humic substances with UV alone was not successful. However, the combination of UV and H_2O_2 showed that the colour can be reduced to acceptable levels. It was also shown that pH did not have any influence on UV oxidation.

Effect of ozone and ozone combinations on THM formation

Tuhkanen *et al* (1994) report the following (*all reference citings taken from Tuhkanen et al*):

Several studies have shown a modest (Tan, 1991) or a large decrease in THM formation potential in final chlorinated water as a result of preliminary ozonation (Jacangelo, 1989), whereas others have reported an actual increase in the THM precursors or chlorinated organic material (Grasso *et al.*, 1989). The important variables are ozone dose, pH, alkalinity, and the nature of organic matter. High pH, the absence of HCO_3^-/CO_3^{2-} ions, high organic material content in water, and the addition of hydrogen peroxide or UV radiation are expected to shift the ozonation mechanism from the selective direct molecular reaction to the nonselective and fast OH radical attack. Ozonation with hydrogen peroxide reduced 60 percent of the trihalomethane formation potential (THMFP), whereas ozonation alone produced no significant reduction in THMFP (Wallace *et al.*, 1988). Mayers *et al.* (1980) gained 30% reduction with O_3/H_2O_2. Duguet *et al.* (1985) studied ozonation of water rich with humic material (TOC 7,5 mg/ℓ). Ozonation (3,2 mg/ℓ O_3) initially increased THMFP, returning to the initial level after 30 minutes of ozonation. Addition of 1 mg/ℓ of hydrogen peroxide caused a 75% THMFP reduction in 30 minutes without an increase in the concentration of the precursors. Similar results were also obtained in pilot and full-scale ozonation experiments by Grasso *et al* (1989). Ozonation with UV-radiation also destroyed THM precursors more effectively than ozone alone (Glaze *et al.*, 1982; Sierka *et al.*, 1985).

c. Ozone followed by biological activated filtration

European water treatment engineers discovered the synergistic effect of combining the unit processes of ozonation and adsorption by granular activated carbon (Constantine, 1982). Carbon beds seemed to hold more organic carbon compounds than adsorption theory predicted to be possible. On detailed investigation, the reason for this phenomenon was found to be a result of microbiological colonization of the carbon beds. Organic compounds were being adsorbed onto the carbon and then were biologically oxidised to water and carbon dioxide, thus freeing the carbon for further adsorption. Furthermore, it is known from several studies that simpler organic molecules, such as the reaction products of ozonation of humic acids, are readily adsorbed. These phenomena have provided much longer in-service life for GAC beds between regeneration cycles and have added to the efficiency and economic attractiveness of the process. Often referred to as biological activated filtration (BAF), this treatment process consists of the following four steps:

-	*Ozonation*	Twenty minutes retention time after ozone contact is necessary. Ozone dosages of about 1 to 2 mg/ℓ. Dissolved oxygen of 2 to 3 mg/ℓ in ozonated water is desirable.
-	*Stabilization*	Much lower lime dosages are required to stabilize the water when the BAF process is used. With the typical unbuffered waters associated with high colours, the use of alum as a coagulant creates a significant lime demand for stabilization.
-	*GAC filtration*	This can be carried out in either gravity or pressure vessels. Twenty minutes detention time in the carbon beds is required.

- *Postchlorination* Because of complete removal of TOC, the postchlorination dosage is lower than it would be for a conventional plant.

For the BAF process, capital costs were estimated at about 10 percent lower than for the conventional process. Operating costs were also substantially lower for the BAF process than for the conventional process. Furthermore, the sludge disposal problem would be greatly reduced with the use of the BAF process. The BAF process also requires far less in the way of chemical dosage, which is important for plants far from industrial chemical suppliers.

The test work by Juby and Botha (1994) has shown that it is possible to achieve good colour reduction by ozonation at 20 - 25 mg/ℓ followed by biologically enhanced filtration, but that complete colour removal was not possible. The variability of the colour in the product water from the filters needs to be considered. Nevertheless, this technology may offer an alternative means of removing colour in water with relatively low colour levels where reduction of 90 - 95 percent of the colour would be sufficient to produce an aesthetically acceptable water. The viability of this process as far as the removal of THMFP is concerned, appears promising when good colour reduction is achieved. A reduction in the chlorine demand for the final disinfection step still requires investigation.

d. Other advanced oxidation processes

In a study by Olson and Barbier (1994), an advanced oxidation process involving ozone and ultrasound was examined in terms of its effectiveness in mineralizing humic substances. By ultrasonically decomposing ozone, greater free radical yields in solution were expected. Sonochemical treatment methods such as this could potentially be extended to refractory electrolytes such as humic materials, whereby the oxidation rates are faster than those obtained with either ultrasound or ozone alone. Any volatile intermediates by this process could potentially be oxidized directly by pyrolysis in the cavitation bubbles.

They found that decolouration rates of fulvic acid solutions during sonozone treatment were slightly more rapid than rates obtained with ozone alone, however, the enhancement is attributed to an increase in the mass transfer of ozone into solution. After the initial decolouration period, more significant differences between TOC removal rates are observed between sonozone treatment and ozone alone. Removal rates of TOC are approximately 10 times faster with ultrasound and ozone at a power input of 27 W and the oxidation rate is not very sensitive to the power input. An important advantage of the sonozone process is that virtually all of the TOC removed during sonozone treatment is mineralized, whereas a significant fraction of the TOC removed by ozone alone is lost as volatile organic carbon compounds. Since ultrasound alone does not affect the TOC content of fulvic acid solutions, the sonozone process extends the application of sonochemical techniques as advanced oxidation processes for refractory organic electrolytes. Like other advanced oxidation processes, however, radical scavengers such as bicarbonate and chloride, can dramatically reduce efficiency.

Investigations into the reduction of colour and THMFP from humic waters by photocatalytic oxidation are presently being carried out by the University of Stellenbosch.

6.1.5 ADSORPTION

Activated carbon

Granular activated carbon is only moderately effective at removing the colour imparted by complex organic acids, and in general only has a limited effectiveness for the removal of humic substances. Although activated carbon has quite a considerable adsorption capacity for hydrophobic, slightly polar organic substances, it can only to a very small extent adsorb large, hydrophillic, or strongly polar organic acids. Consequently, naturally polar organic molecules such as humic substances, or those formed subsequent to chemical oxidation, remain either unadsorbed, or partially adsorbed. There is an almost immediate breakthrough of humic and fulvic acids observed from carbon columns and pilot trials required an effective carbon dose in the range of 40 - 55 mg/ℓ in order to achieve a 50% or greater TOC removal (Lambert and Graham, 1989). Batch systems also showed an activated carbon adsorption of humic substances ranging from about 1,02 - 33,0 mg/g.

Although adsorption is often the only mechanism referred to in granular activated carbon treatment processes, it is only one of the dissolved organic removal mechanisms, and biodegradation processes often play an equal or more important role. Biological activity naturally occurs in granular activated carbon filter beds by assimilating the biodegradable matter in the influent water. This has the effect of improving the TOC removal by an additional 10 - 15%, and extending the filter life prior to breakthrough. As mentioned in section 6.1.4 (c) above, there is currently much interest in further improving by enhancing the microbial activity on the carbon contact beds by preoxidising the influent water with ozone.

Activated alumina

The ability of alumina to adsorb organic substances has been known for a long time and it was used for the separation of organic acids as early as 1906 (Lambert and Graham, 1989). Activated alumina was suggested as an adsorbent for the removal of dissolved organics from water in the 1950's, when it was observed that while alum flocculation removed only 60% of the organic matter from boiler feeds, alumina was 90% effective. Although activated alumina has proved to be very successful in purifying wastewaters laden with organic matter, especially those from wood pulp bleaching plants and paper factories, It has received little attention for the treatment of potable water supplies containing organic substances.

6.2 DISINFECTION

The purpose of disinfecting water supplies is to prevent the spread of waterborne diseases. Many instances have been reported in various countries of waterborne diseases occurring in small and large communities as a result of insufficient disinfection. It is essential that pathogenic and other organisms should be destroyed before water is distributed for general use. Disinfecting agents that can be used for this purpose include chlorine, chlorine dioxide, ozone, ultraviolet irradiation, heat and ultrafiltration. These disinfection methods are discussed below, with specific emphasis on chlorine, as it is the disinfectant used without exception in colour removal treatment plants in the Cape.

a. Chlorine

Overview of chlorination

Chlorine is the disinfectant most commonly used in the treatment of water for potable use. It may be added in the form of a gas or as sodium hypochlorite ($NaOCl$), calcium hypochlorite ($Ca(OCl)_2$) or chloride of lime. When applied at the end of the purification process it is a finishing touch which serves as a final safety barrier against pathogenic organisms, and not the sole step in purifying a badly infected water supply. Prechlorination, however, can perform a number of other functions, For example, it oxidises iron and manganese, and controls algae and slime forming organisms in water treatment plants.

The following terminology is commonly used in chlorination practice:

- *Free chlorine or available free chlorine*

  Free (available) chlorine in water will be present as a mixture of elemental chlorine (Cl_2), hypochlorous acid ($HOCl$) and the hypochlorite ion (OCl^-), the proportions of which depend on the pH of the solution. The *free chlorine residual* is the amount of free chlorine available for further disinfection after breakpoint (see later) has been achieved.

- *Combined chlorine residual*

  When ammonium ions are present in chlorinated water, mono-chloramine, di-chloramine and nitrogen trichloride (highly volatile and toxic) are formed. These are also disinfectants, although less effective than chlorous acid. The *combined (available) chlorine residual* is the sum of all such chlorinated nitrogenous products, distinguishable by analytical methods.

- *Total chlorine residual*

  The *total chlorine residual* refers to the sum of the combined and free chlorine residuals.

- *Chlorine demand*

  Chlorine combines with and oxidises other substances in water. The chlorine demand is the amount of chlorine used up in the process. It is measured as the difference between the amount of chlorine applied to a treated supply and the resultant total chlorine residual. It can also be regarded as the excess chlorine required to produce a free chlorine residual. The chlorine demand of a water varies with the amount of chlorine applied, pH, time of contact and temperature. Any value given for chlorine demand is merely a rough indication unless all conditions are specified. The chlorine demand of water increases with higher concentrations of nitrogenous compounds, organic substances (such as organic colour), and reducing compounds (iron, manganese, etc).

Chlorination may be applied in three different ways, as follows:

- *Normal chlorination*

  Normal chlorination entails the addition of chlorine until the desired residual concentration is obtained after a fixed contact period.

- *Chloramination*

  In the *chloramination process* ammonia is added to the water, followed by sufficient chlorine to provide the desired concentration of combined chlorine in the form of chloramine. The process requires a long contact time to ensure complete disinfection.

- *Superchlorination*

  Superchlorination is usually applied in cases where undesirable organic substances have to be destroyed. The chlorine dosage should be sufficient to satisfy the chlorine demand, *i.e.* to react chemically with and destroy the organic substances, which produce taste and odours, and thereafter to provide a residual of free available chlorine. The breakpoint is that point on a chlorine dosage curve where the chlorine demand has been satisfied and any chlorine which is subsequently added remains in solution as free residual chlorine and not as chloramines or other forms of combined available chlorine.

Chlorination in colour removal treatment plants

In colour removal treatment plants, the following are important aspects regarding the use of chlorine as disinfectant:

- chlorination of colour causing compounds and other organic substances in the water may result in the formation of undesirable disinfection byproducts, some of which have been found to be potentially carcinogenic (cancer forming). One such class of compounds is the trihalomethanes (THMs), consisting of chloroform and related substances. Limits have been set for these compounds in drinking water. There are other undesirable chlorinated substances, which are however less easily measured than THMs. THM concentrations are therefore sometimes used as an indication of the total organo-chlorine content of a water. When using chlorine as means of disinfection of coloured waters, it is therefore important to ensure that the organic substances that will form THMs on chlorination, measured as trihalomethane formation potential [THMFP], be effectively removed in the coagulation and filtration processes. In the USA and Europe strict regulations are enforced to ensure that disinfection byproducts in the final water to the consumer are kept to an absolute minimum. This is accomplished by using enhanced coagulation (coagulation at higher dosages than is necessary for only, say, colour removal), activated carbon adsorption, and membrane processes.

- suspended matter may envelop bacteria, thereby shielding them from attack by chlorine. It is hence very important that the sand filtration process effectively removes turbidity from the water to less than 1,0 NTU (but preferably even lower) before chlorination is applied. This will not only ensure sufficient chlorination, but also the removal of protozoan cysts such as *Giardia* and *Cryptosporidium*.

- waters with low alkalinity and pH values below 7,2 are disinfected more readily than waters with high pH values. For coloured waters, more efficient disinfection will thus be obtained by chlorinating partially ahead of the filters and for the remainder chlorinating the filtered water before lime is added for final stabilization, than when the stabilized water is chlorinated (at a pH of 9,0 and above).

- chlorinating the settled water before filtration will ensure that the filter media are kept free from biological growth and that iron and manganese (if the pH is raised) can be precipitated.

- if iron and manganese are not removed sufficiently before final chlorination is applied, it will exercise a chlorine demand

- the rate of disinfection increases with rising temperature, but on the other hand, chlorine is more stable at lower temperatures. The fact that it remains available for a longer period at low temperatures compensates for its slower reaction rate.

- the contact period is of cardinal importance. The minimum period is 10 to 15 minutes, but should preferably be several hours because the shorter the contact time, the higher the dosage of free available chlorine will be that is required for effective disinfection.

b. Chlorine dioxide

Although chlorine is most widely used in water treatment for disinfection because of its bactericidal effectiveness, low cost, convenience and relatively long-life residual, in many cases the use of chlorine dioxide (ClO_2) may be a viable alternative to chlorine because a minimal amount of chlorinated organics are formed after disinfection with chlorine dioxide.

Chlorine dioxide is an unstable gas which is explosive at temperatures higher than -40 °C; therefore it must be generated at the point of use.

Chlorine dioxide theoretically has about 2,5 times the oxidizing power of chlorine. However, the oxidizing capacity of chlorine dioxide is not all used in water treatment practice because the majority of its reactions with substances in water only reduce the chlorine dioxide to chlorite (ClO_2^-), except under special conditions. High levels of chlorine dioxide, and particularly of chlorite, may have adverse effects on the health of consumers. Furthermore, chlorine dioxide is comparatively expensive.

c. Ozone

Ozone is used in several European countries to disinfect water for potable use, and has been found effective as an oxidizing agent for colour reduction (see earlier in this chapter) and for substances that cause tastes and odours. The gas is unstable and must be prepared at the point of application. By subjecting dried, filtered air to the silent electrical discharge of high tension alternating current, some of the oxygen is converted to ozone (O_2 to O_3).

After about 30 minutes contact time the remaining ozone changes back to oxygen, with the result that no ozone taste or odour is retained in the treated water. However, there is no long lasting disinfection. Because of the method of preparation, ozone is more expensive than chlorine, the installation requiring considerable capital outlay.

d. Other methods of disinfection

- <u>Ultraviolet irradiation</u>

This method can be used to treat small volumes of water, but the water should be clear so that the rays can penetrate it. There should be no dissolved iron, even in trace quantities, since dissolved iron will absorb ultraviolet light rays. Ultraviolet irradiation has virtually no influence on the chemical composition of the water. It also does not provide a disinfection residual.

- Heat

Effective disinfection is obtained by boiling water, as all vegetative bacterial cells are destroyed at temperatures higher than approximately 80°C. This method is, however, not economically justified and restricted to small scale application.

- Ultrafiltration

Small quantities of water may be purified by filtering it through ceramic candles. If the candles are impregnated with silver, the unit produces a water which may be considered as disinfected. However, recent research has revealed that, while the silver-impregnated unit does eliminate bacteria, it does not destroy viruses.

Disinfection practices at treatment plants surveyed in this study

The final water from all the treatment plants is chlorinated before it is pumped to the clean water reservoirs and the distribution network. At 7 of the plants the water is chlorinated before lime addition for stabilization, while at the other 11 plants, the water is first stabilized before chlorine is dosed. Two of the smaller plants dose liquid calcium hypochlorite, while all of the others use gaseous chlorine. Dosages are adjusted to give a free chlorine residual in the final water leaving the plant ranging from 0,3 - 1,0 mg/ℓ. Only at the larger plants is further chlorination done at the service reservoirs. Measurement of disinfection by-products, in particular trihalomethanes, is only done occasionally at the large treatment plants, and not at all at the smaller treatment plants because of the high cost involved.

6.3 STABILIZATION

One of the main problems experienced with the use of coloured waters as source for drinking water, is the aggressive attack on and corrosion of pipes and materials containing these waters. Economic costs in maintaining distribution systems have not been estimated in South Africa, but they must be substantial. A study in this regard is long overdue, but discussions with municipal officials in charge of water supplies, and with consumers, have forced the conclusion that problems with corrosion and aggression in distribution systems in soft water areas, are indeed widespread (Loewenthal, 1996). This has also been confirmed during the survey of colour removal treatment plants in the Cape in this study. In many instances, these problems can be minimised by relatively simple chemical pretreatment, as described below.

Aggression

Aggression is the designation given to the phenomenon whereby water attacks the cement matrix of cement and concrete lined structures. Two distinct aggressive processes have been identified:

- The water has chemical characteristics that cause dissolution of some of the minerals in the cement matrix
- The water contains sulphate species which might react chemically with some of the minerals in the cement matrix to form products which cause physical disruption of the matrix.

The first one is generally the controlling mechanism in soft water environments (coloured water).

For chemical characteristics of aggressive waters, the terms *undersaturation, supersaturation and saturation* with respect to calcium carbonate describe chemical states in a water such that it respectively dissolves solid calcium carbonate (undersaturation), precipitates solid calcium carbonate out of solution (supersaturation) and neither precipitates nor dissolves calcium carbonate (saturation).

Corrosion

Corrosion of the metal components of pipes carrying water is the result of oxidation and reduction reactions at sites on the metal-water interface, by the formation of electro-chemical cells each with an anodic and cathodic area. At the anode metal molecules lose electrons to form metal ions which pass into solution. At the cathode the electrons (generated at the anode) pass from the metal (electron donor) to some chemical species (electron acceptor) in the water adjacent to the cathode; this is usually molecularly dissolved oxygen, if present. Depending on the circumstances, the reactions may cause continuous dissolution of the metal into the water at the anode (corrosion), or may give rise to precipitation of minerals over the anode and cathode, thereby minimising the areas of the active electro-chemical sites and the rates of the reactions, and eventually stopping the corrosion completely (passivation of the surface).

Chemical treatment for stabilization

A stable water is essentially one the composition of which does not change when in contact with crystalline calcium carbonate, *i.e.* is saturated with respect to calcium carbonate, as described above. In the water treatment industry the term stabilization has, somewhat loosely, been broadened to describe the process of producing an over-saturated water in order to minimise it's aggressive and corrosive tendencies.

Protection of concrete and fibre-cement pipes, the major consideration, is relatively easy to achieve and involves increasing calcium and/or alkalinity concentrations to values that give a small degree of super-saturation, say between 0,5 and 4 mg/ℓ calcium carbonate precipitation potential. The computer program STASOFT, available from the Water Research Commission and in the process of being further developed, gives guidance in respect of concentrations required.

If the calcium content of the filtered water is low, the preferred treatment chemicals are slaked lime and carbon dioxide. However, in the case of highly coloured raw waters, sufficient lime may have been added in the coagulation stage to raise the calcium content considerably and so allow the use of sodium carbonate to provide the necessary increases in alkalinity, pH and carbonic species.

There is room for further investigation of this approach, which may be attractive for small plants where the ease of dosing a solution may outweigh any extra sodium carbonate cost - it is difficult to reliably dose small amounts of lime. The critical requirement here is that the settled or filtered water has a sufficient carbonic species content so that the final pH is not too high when enough sodium carbonate has been added for the required minimum alkalinity. There may be several ways of achieving this.

Small plants often have operational and cost constraints which influence the choice of chemicals but, given the size of the investment in distribution pipework, it should always be possible to find some combination which will provide the required result. With very small supplies or when current treatment only consists of disinfection, limestone beds, although not providing complete protection, will bring about an improvement.

Protection of metals against corrosion is a more complex matter. The soft brown waters of the Cape are notoriously corrosive towards iron, steel and lead. Local practice has long since adapted to this fact by avoiding the use of these materials. Steel mains are given cement linings and the main plumbing materials used in the area are copper, brass and, more recently, polypropylene or polythene. The emphasis should therefore be on the protection of these materials.

Minimising corrosion of copper is mainly a matter of increasing the pH above about 8,1 without having too high an alkalinity - high alkalinity has recently been shown to increase corrosion of copper (Edwards *et al*, 1996).

Dezincification of brass, another local problem, has largely been dealt with by the development and use of dezincification-resistant brasses. If other brasses are used, dezincification problems, such as blockages and deposits in tee-pieces and elbows are to be expected, especially at the outlet to water heaters.

Protection of steel pipes by over-saturating the water with calcium carbonate is more difficult to achieve as over-saturation is not the only requirement. High alkalinity values, at least 50 mg/ℓ as $CaCO_3$ and probably much more, depending also on chloride and sulphate content, are needed. None of the plants surveyed made any attempt to achieve these conditions. This approach is only considered economical and desirable in areas where the raw water has in any case nearly the right composition and where copper has not ben extensively used as a plumbing material. Steel pipework should therefore be avoided in the Western and Southern Cape, unless special local anti-corrosion measures are adopted. Good quality stainless steels provide no problem.

In summary, if stabilization is aimed at protecting fibre-cement, concrete and cement-lined pipes, where the requirements are relatively modest, corrosion of the most commonly used plumbing metals in the Western Cape should at the same time largely be minimised.

Stabilization practices at treatment plants surveyed

At all the plants, an alkali is dosed into to the final water (either before or after chlorination) to prevent or reduce corrosion or aggression of the distribution system. Lime is dosed in all but one plant, where soda-ash is used. In 11 of the treatment plants, just enough lime is dosed to reach a certain pH (usually around 9,0). The alkalinity of the water is then about 15 - 30 mg/ℓ and the precipitation potential 0 to 1 mg/ℓ as $CaCO_3$. At the remainder, lime and carbon dioxide are added.

6.4 SLUDGE TREATMENT AND DISPOSAL

At most of the treatment plants, sludge from the settling tanks is not treated before disposal. The sludge is normally fed into a holding dams or ponds. At some larger treatment plants, the sludge is dewatered to reduce the volume before being disposed of. Centrifuges are used for dewatering, after addition of a polyelectrolyte to enhance the dewatering process. The supernatant is recycled to the treatment works.

Because of the importance of sludge treatment and disposal at Cape colour removal treatment plants, this aspect is dealt with in more detail in a separate chapter (Chapter 9).

CHAPTER 7

OPERATION AND MONITORING OF TREATMENT PLANTS

7.1 NEED FOR AND IMPORTANCE OF A WELL-DESIGNED OPERATIONAL CONTROL AND MONITORING PROGRAMME

Proper monitoring is essential for efficient and economical operation of treatment plants. A treatment plant, however well it has been designed and constructed, is only as good as the way it is operated.

During the survey of full-scale plants treating Cape coloured water, it became apparent that monitoring of the plants, especially the smaller ones, was grossly neglected. The general result of this is either that the quality of the final water to the consumer often does not comply with generally accepted guidelines for drinking water (SABS; WHO; Department of Health Water Quality Guidelines), or is operated uneconomically because of too high chemical dosages, water wastage because of too short filter runs, and/or energy wastage.

Monitoring programmes for treatment plants are therefore needed to ensure cost-efficient treatment of water for the consumers, and a high quality drinking water complying with the national specifications and guidelines.

7.2 OPERATIONAL CONTROL REQUIREMENTS

7.2.1 Coagulation control

As the coagulation process forms the core of conventional treatment for colour removal (chemical precipitation followed by phase separation), it is clear that it requires careful monitoring and control. Close monitoring and control of coagulation conditions is also essential to minimize the residual metals (aluminium, iron and manganese) in drinking water.

The parameters requiring control are coagulant dose and pH, for which there are three distinct necessary actions at any given treatment plant:

1. Development of local guidelines for dose and pH selection, suited to the particular plant - a long term action.

2. Application of these guidelines in the selection of a target dose and pH value for prevailing conditions - an hourly, daily or weekly action.

3. Maintenance of conditions as closely as possible to the target values - a continuous action.

These actions may be executed with varying degrees of thoroughness, depending on the size of the plant and available facilities and staff. At very small plants they may be carried out by the same person, but should nonetheless be kept distinct. Thus, target doses are changed when raw water quality changes, guidelines are only changed when it is very clear that they inadequately allow for some particular raw water condition and most attention is directed at ensuring that target doses are in fact being delivered as expected.

a. <u>Development of local operational control guidelines</u>

These guidelines are essentially a distillation of all relevant available information. Much of this comes from research papers, WRC reports, experience with similar raw water supplies etc. There is currently a WRC project under way aimed at improving knowledge of the coagulation characteristics of the Cape brown waters.

However, it is wise to confirm the relevance of this information in the treatment of any given local water and this is best carried out in a systematic manner by means of jar or beaker tests, which are later described. Depending on the thoroughness required, a fair amount of time and sophisticated analytical methods may be needed. Mostly such work is carried out by central laboratories or consultants but, if these are not to hand, guidelines from nearby plants can be employed and modified in the light of experience or the tests can be simplified and carried out by plant staff.

Even when a large amount of information about a given raw water is available it is still necessary for the management of the treatment plant to decide on the level of treatment to be applied. There is usually no easy way to select an optimum dose as removal of organic matter generally increases as the dose goes up. However a law of diminishing return applies and higher dosages usually mean an increased salt content and hardness. Local factors such as budgetary constraints have to be taken into account.

For the results to be of any use in the day to day operation of a plant they have to be summarised in some easily used form. Fortunately, with brown waters, required coagulant dosages seem to be mainly related to the amount of organic matter present, as measured by colour or UV absorbance. The guideline can then take the form of a graph of dosage versus colour or a factor to be multiplied by colour etc. There may be a need for several such figures if the raw water supply comes from more than one source or varies widely in quality. For pH it is generally enough to specify a single target value for a given raw water and coagulant.

b. **Selecting a target dose and pH**

If local guidelines have been formulated, this is merely a matter of applying them by measuring colour or UV absorbance and calculating the required dose. If done by the plant manager the targets can be displayed on a board.

c. **Maintaining target conditions**

The main task of plant operators is to ensure that target conditions are maintained, in spite of feeder blockages, raw water flow changes etc. while at the same time keeping an eye open for raw water quality changes.

An excellent simple tool for keeping a general check on the success of this operation is to take a beaker full of coagulated water at regular intervals, stir it for 10 or 15 minutes by means of the stirrer employed for jar tests and then allow to settle. With a white card at the back, residual colour as well as settlement are easily observed.

Shift operators should have the right to change target doses on a temporary basis if trouble is experienced. When the cause is identified the target value can be re-assessed.

The target pH should seldom if ever be changed and attention should be focused on checking, acid-cleaning and re-buffering the pH meters. There should always be two pH meters available. If a recorder is in use, a laboratory meter should be used to check it. Glass electrodes give a slow response when old, especially with soft waters, and when agreement cannot be reached between meters, new electrodes should be tried. Porous plugs used for salt bridges on reference electrodes become clogged and can be difficult to clean - acid cleaning should first be tried and the plug then replaced if that is possible.

When checking pH meters, it should be noted that the pH of the dosed water usually increases with time, eventually settling down, and the recorder may therefore show a lower figure than the bench meter, especially if the recorder electrode has to be placed very close to the dosing point. In such cases it may be advisable to adjust the recorder to read the same as the bench meter.

In controlling the pH of the coagulation process to obtain optimum colour removal, it is very important that the levels of residual metals should also be monitored during tests to establish the optimum pH range. This is done by varying the coagulation pH at optimum coagulant dosage in beaker tests and determining the metal residual at each pH level. This should be done when using a new water source for treatment or when the quality of the raw water source changes significantly. The optimum pH range must then be selected for good removal of colour but be within acceptable ranges of metal residuals (alum and/or iron).

An example of such a metal residual (solubility) curve is presented in Figure 7.1 (for a Cape Town Municipality treatment plant [Morrison, 1996]).

7.2.2 Control of settling processes

The only control of the settling process that can be exercised is by changing the frequency and duration of desludging. This would require some means of observing or monitoring the depth of the sludge blanket in the settling tank. A number of methods to do this have been applied, *e.g.* using discs or rods to observe light penetration, or using light sensors at various depths. In most instances, the sludge depth is monitored by direct visual observation of the sludge blanket in the settling tanks by the plant operator during daytime.

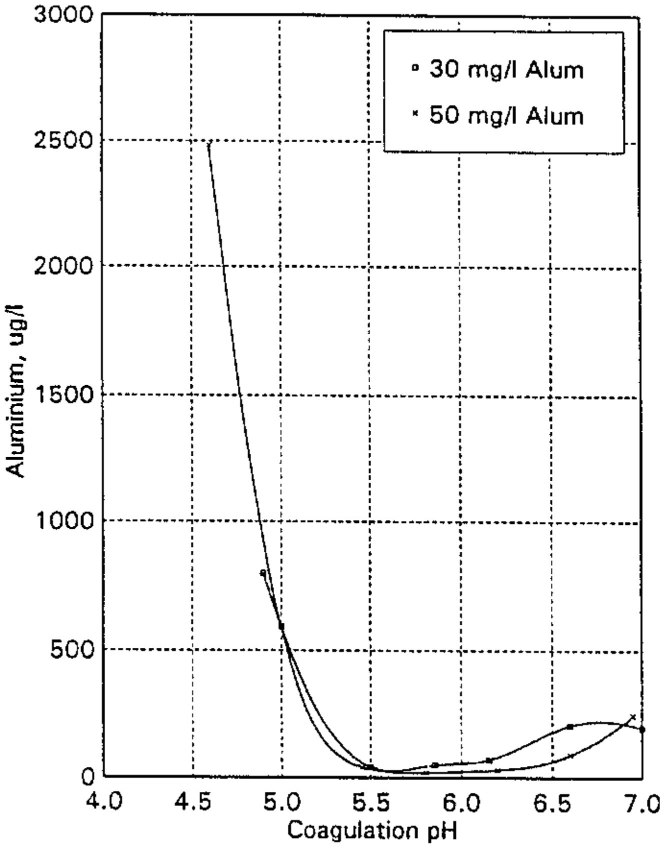


Figure 7.1 Example of a metal residual (solubility) curve

7.2.3 Control of filtration

The decision as to when the filters should be backwashed is made by observing the head loss over the filter and/or the quality of the filtrate. However, as was pointed out in Chapter 6, most plant managers of Cape coloured water treatment plants find that routine backwashing of filters based on experience provides the most practical option.

Filter backwashing can be controlled by monitoring the quality of the dirty water discharged during backwashing. By determining the suspended solids (or turbidity) of the discharged water at time intervals from commencement of backwashing, the process controller will be able to determine what the optimum range of backwash times for his filters are.

7.2.4 Control of stabilization

The stabilization process is usually carried out in one or two stages, depending on the chemicals used and degree of stabilisation desired. On-line or frequent manual measurement of alkalinity, pH and, sometimes, conductivity are used for control purposes as indicated below.

a. Partial stabilization

A partially stabilised water results if, after sufficient lime or sodium carbonate has been added to filtered water to raise the pH to the allowed limit, the water is still under-saturated with respect to calcium carbonate. Whether or not this happens depends on the carbon dioxide content of the filtered water - low values giving under-saturation.

This process is controlled by monitoring the pH of the water after lime or sodium carbonate addition and sufficient mixing has taken place. For a specific water, a target pH is set. As SABS 241 of 1984 recommends a maximum pH limit of 9,0 for drinking water, the target pH should normally not be higher than about 9,2 to ensure a pH value of less than 9,0 at the consumer's tap.

Plants that practice partial stabilization need only determine alkalinity and calcium content occasionally when the quality of the raw water changes or it is desired to calculate the calcium carbonate precipitation potential by means of the STASOFT programme. The pH of the final water should be monitored by continuous in-line (chart) measurement, or on an hourly basis.

b. Full stabilization

Full stabilisation is either a one- or a two-stage process. A one-stage process results when there is sufficient carbon dioxide in the filtered water, to give a saturated water of pH of 9.2 or less, after adding sodium carbonate or lime. Otherwise an additional carbon dioxide dosage stage will be required.

For the single stage process, either pH or alkalinity can be used to control the amount of alkali added. As pH is easily measured on a continuous basis it is most often used. Alkalinity should then also be measured at least once a shift to detect changes in raw water quality.

With a two stage process, target values for both alkalinity and pH must be chosen. More than one combination of alkalinity and pH will probably suffice and STASOFT can be used to assist in the choice.

Use alkalinity to control the amount of lime added. Automatic control can be based on conductivity measurement, as the conductivity of the limed water before addition of carbon dioxide is proportional to the amount of lime added.

Carbon dioxide dosage control is based on pH measurements, after the addition point. As the final pH is sensitive to small changes in the ratio of carbon dioxide to lime, measurement should be at frequent intervals and preferably continuous.

7.2.5 Disinfection control

The disinfection process is controlled by taking regular samples of the final water leaving the plant and analyzing for free chlorine residual. This should preferably be done on an hourly basis. It is recommended that chlorine residuals also be determined on a regular basis at selected points in the distribution network to ensure that the initial dosage of disinfectant at the treatment plant is sufficient, and to establish whether additional disinfection at service reservoirs might be necessary.

The efficiency of disinfection must also be controlled by taking samples of the final water at the plant (and occasionally in the distribution network) and analyzing the microbiological quality of the water, *i.e.* determination of total plate counts, total coliforms and faecal coliforms. This microbiological control should be done at least on a monthly basis at small to medium-sized plants, and weekly at the larger plants.

7.3 PROPOSED MONITORING PROGRAMMES

Every water treatment plant treating water for drinking purposes should have a monitoring programme to ensure that the water it produces is safe for human consumption. The extent of the monitoring will normally depend on the size of the plant or the number of persons served. A comprehensive record should be kept of the data as part of the monitoring programme.

Because of financial constraints, both in terms of purchasing measurement apparatus or appointing suitable operating staff, small treatment plants normally cannot implement a monitoring programme similar to that of the larger water suppliers. However, every treatment plant should have at least an absolute minimum monitoring programme consisting of daily analysis of pH and free chlorine residual of the final water to ensure a safe and wholesome supply of drinking water to the consumer.

The recommended monitoring programmes for small to medium-sized plants (treating less than 20 Mℓ/day) and for large plants (treating 20 Mℓ/day or more) are given in Tables 7.1 and 7.2 on the following pages. It should be noted that frequency of monitoring the quality of the raw water depends on what the raw water source is. For a large reservoir (dam), weekly monitoring may be sufficient (as indicated in the tables), but if the water is withdrawn from a river, the quality may change hourly, and more frequent analysis of raw water quality will be necessary.

Monitoring by external consultants

Where it is not feasible for a plant owner to have the overall monitoring done by plant personnel themselves, then a consultant can be contracted to do the monitoring on their behalf on a monthly basis. The monitoring done by this consultant will be additional to the basic monitoring which must be performed by the plant process controller(s).

Table 7.1 Recommended monitoring programme for small to medium-sized colour removal treatment plants

RECOMMENDED MONITORING PROGRAMME
For small to medium-sized treatment plants
(treating less than 20 Mℓ/day)

Measurement	Sample	Frequency
pH	Coagulated water	Hourly, but preferably chart
	Final water	Hourly or chart
Colour (true) or UV absorbance	Raw water	8-hourly
	Settled water	Monthly
	Filtered water	Monthly
	Final water	8-hourly
Turbidity	Raw water	Weekly
	Settled water	Daily
	Filtered water	Daily
	Final water	8-hourly or chart
Alkalinity	Final water	4- hourly
Ca, Mg hardness	Filtered water	Monthly
Total hardness	Final water	Monthly
Conductivity	Raw water	Monthly
	Final water	Monthly
Iron	Final water	Monthly
Aluminium	Final water	Monthly
Free chlorine residual	Final water	4-hourly
Total plate count	Final water	The frequency is prescribed by DWAF and depends on the population served
Total coliforms	Final water	
Faecal coliforms (E.Coli)	Final water	

Table 7.2 Recommended monitoring programme for large colour removal treatment plants

RECOMMENDED MONITORING PROGRAMME For large treatment plants (treating 20 Mℓ/day or more)		
Measurement/Procedure	**Sample**	**Frequency**
pH	Raw water Coagulated water Final water	Weekly Hourly and chart Hourly and chart
Colour (true) or UV absorbance	Raw water Coagulated water Final water	8-hourly Monthly 8-hourly
Turbidity	Raw water Settled water Filtered water Final water	Weekly 8-hourly or chart 8-hourly or chart 8-hourly or chart
Alkalinity	Raw water Final water	Weekly 4-hourly
Total hardness	Filtered water Final water	Weekly Weekly
Conductivity	Raw water Final water	Weekly Weekly
Iron	Final water	Weekly
Aluminium	Final water	Weekly
Trihalomethanes	Final water	Monthly
Free chlorine residual	Final water	Hourly
Total plate count; total coliforms; E.Coli	Final water	As prescribed by DWAF

7.4 MINIMUM LABORATORY EQUIPMENT REQUIRED FOR THE PROPOSED MONITORING PROGRAMMES

To implement the monitoring programmes as proposed above, the treatment plant management should set up and equip a laboratory at the treatment plant to do the required basic physico-chemical analyses on site, apart from the other analyses that can be done at a centralised laboratory of the authority, or by an external consultant.

The minimum laboratory equipment required at the treatment plants are given in Tables 7.3 and 7.4 for small to medium-sized and large plants respectively.

7.5 SAMPLING, ANALYSIS AND REPORTING

a. Sampling

It is not possible to specify detailed procedures for collection of all types of water samples because of varied purposes and analytical procedures. More detailed information on sampling for analysis of certain quality parameters for coloured water is given in Appendix D. General considerations for collection and preservation of water samples are given in Standard Methods. A brief extract from these general sampling considerations is given below.

The objective of sampling is to collect a portion of material small enough in volume to be transported conveniently and handled in the laboratory while still accurately representing the material being sampled. This implies that the relative proportions or concentrations of all pertinent components will be the same in the samples as in the materials being sampled, and that the sample will be handled in such a way that no significant changes in composition occur before the tests are made.

Table 7.3 Minimum laboratory equipment requirements for small to medium-sized plants (treating less than 20 Mℓ/d)

Equipment/Apparatus	Reason needed	Approximate cost (R)
pH meter (Preferably in-line in flocculation chamber and in final water, and/or a good quality bench-model)	Accurate control of coagulation pH for optimised colour and metals removal Control of stabilization of final water	R 2 000 - R 5 000
Colorimeter	Measurement of raw water colour to check coagulant dosage Measurement of final water colour for quality control	R 7 000 - R 9 000
Turbidimeter	Control of the settlement and filtration processes	R 7 000 - R 13 000
Apparatus and glassware for performing titrations	Alkalinity measurements for stabilization control	R 250 - R 500
Paddle stirrer	To control the flocculation process	R 3 500 - R 4 200

Table 7.4 Minimum laboratory equipment requirements for large plants (treating more than 20 Mℓ/d)

Equipment/Apparatus	Reason needed	Approximate cost (R)
pH meter (Preferably in-line in flocculation chamber and in final water with two additional bench models)	Accurate control of coagulation pH for optimised colour and metals removal Control of stabilization of final water	R 2 000 - R 5 000
Spectrophotometer	Measurement of UV absorbance, colour, metals, Ca and Mg, and chlorine residuals, for process control and quality assurance of final water	R 30 000 - R 50 000
Turbidimeter	To control the settlement, filtration and stabilization processes	R 7 000 - R 13 000
Conductivity meter	Quick check for chemical dosages	R 3 000 - R 5 000
Apparatus and glassware for performing titrations	Alkalinity measurements for stabilisation control	R 250 - R 450
Beaker test equipment (stirrer and suitable beakers)	To perform beaker tests and to control the flocculation process	R 7 000 - R 13 500

A sample may be presented to the laboratory for specific analyses with the collector taking responsibility for its validity. Often, the laboratory conducts or prescribes the sampling programme, which is determined in consultation with the user of the test results. The sampling programme defines the portion of the whole to which the test results apply. Account must be taken of the variability of the whole with respect to time, area, depth, and in some cases, rate of flow.

Methods of sampling

Manual sampling	Manual sampling involves no equipment but may be unduly costly and time-consuming for routine or large-scale sampling programmes.
Automatic sampling	Automatic samplers are being used increasingly. They are effective and reliable and can increase significantly the frequency of sampling. Various devices are available but no one sampler is universally ideal.

Preservation

Complete and unequivocal preservation of samples is a practical impossibility. Regardless of the sample nature, complete stability for every constituent never can be achieved. At best, preservation techniques only retard chemical and biological changes that inevitably continue after sample collection. Changes that take place in a sample are either chemical or biological.

Some determinations are more likely than others to be effected by sample storage before analysis. Certain cations are subject to loss by adsorption on, or ion exchange with, the walls of glass containers. These include aluminium, iron and manganese, which are best collected in a separate clean bottle and acidified with nitric acid to a pH below 2,0 to minimize precipitation and adsorption on container walls.

Iron and manganese are readily soluble in their lower oxidation states but relatively insoluble in their higher oxidation states; therefore, these cations may precipitate out or they may dissolve from a sediment, depending upon the redox potential of the sample. Residual chlorine is reduced to chloride and must be determined immediately after sampling. Colour and turbidity may increase, decrease or change in quality, although the colour of humic materials is fairly stable.

b. Analysis

Procedures and methods for the analysis for the various water quality parameters required for process control and quality assurance in colour removal treatment plants, are given in Appendix D.

c. Reporting

Records of daily, weekly and monthly monitoring of water quality variables should be kept in books at the treatment plant and thereafter stored on computer to facilitate regular and future processing of data. The results of plant monitoring programmes should be summarised on a monthly basis in the form of reports, and submitted to the engineers for review and taking any actions as may be required. Where the services of external consultants are employed for assurance of quality control and optimum plant performance, the daily monitoring data will be processed and interpreted and proposals made as to how the plant can be operated more cost-efficiently, where appropriate.

CHAPTER 8

UPGRADING CONSIDERATIONS

8.1 INTRODUCTION

The need to upgrade an existing water treatment plant can be for one or more of the following reasons:

- to increase the treatment efficiency
  (provide better quality final water at optimum cost)
- to increase the capacity
  (supply more treated water)
- to change the type or purpose of treatment
  (changed raw water quality)

The issues to be considered when upgrading a colour removal treatment plant are listed below.

8.2 IMPROVING TREATMENT COST-EFFICIENCY

8.2.1 Better process control

- Chemical dosing

- Settling tank desludging

- Filter backwash

8.2.2 Control of flow rates

- <u>Flows more balanced - never too high</u>

8.2.3 Improve individual process efficiency through physical changes, retrofits or new processes

- <u>Improve settling</u>
- <u>Improve floc formation (flocculation)</u>
- <u>Rapid mixing system</u>
- <u>Filter media</u>
- <u>Inlet and outlet arrangements</u>
- <u>Chlorine contact tank and residence time</u>

8.2.4 Regular and correct monitoring for process control

8.2.5 More reliable equipment

- <u>Dosing pumps</u>

8.2.6 Handling of process upsets

- <u>Correct procedure</u>
- <u>Timeous action</u>

8.2.7 Add polishing process

8.2.8 Add pre-treatment process

8.2.9 Better reporting

8.2.10 Regular optimisation of process by consultant

8.3 INCREASING TREATMENT CAPACITY

8.3.1 Need for increased pumping of

- <u>Raw water</u>
- <u>Treated water</u>

8.3.2 Increase reservoir capacity

8.3.3 Increase hydraulic capacity for channel flows, pipe flows, retention times

8.3.4 Increase unit process to keep flow rates (settling rates, filtration rates, Cl_2 contact time) to within design limits, by

- <u>Temporary measures</u>
- <u>Retrofitting</u>
- <u>Expansion</u>
  - new reactors
  - new structures

8.3.5 Replace instruments/meters to handle higher flow rates

8.3.6 Modular expansion

- <u>Package plants</u>
- <u>Series filtration</u>

8.4 PROCESS ALTERATION OR ADDITION

8.4.1 Add/remove unit processes

8.4.2 Change treatment train

8.4.3 Provide balancing facility

- Earth dam between river and plant

8.4.4 Substitute unit processes

8.5 TECHNOLOGIES/MEASURES AVAILABLE FOR UPGRADING TREATMENT PLANTS

Specific measures (in addition to using any of the technologies listed above) can be taken for upgrading existing colour removal treatment plants, either to increase its capacity or to improve the quality of the treated water, or to make provision for changes in raw water quality.

A number of such measures are listed below as example:

- providing improved rapid mixing and/or flocculation systems
- retrofitting existing settling tanks with inclined plates or tubes
- changing filter media in rapid sand filters
- providing affordable process control instrumentation
- improve backwashing facilities of filters.

CHAPTER 9

SLUDGE TREATMENT AND DISPOSAL

The disposal of waste sludges from colour removal treatment plants in the Cape presents a major problem to the water suppliers. There is a growing realization that these waste streams may present a major pollution source and that it should be disposed of in a manner which is acceptable to the receiving environment. Because of the poor dewaterability of these sludges, treatment and disposal costs may be high and constitute a significant portion of the total treatment costs at a colour removal treatment plant.

At the seminar/workshop on ***Treatment of Coloured Water for Potable Use*** that was held in Mossel Bay in October 1996, the treatment and disposal of sludges from treatment plants treating organically coloured water was ranked the second highest priority for further research to provide more cost-efficient and user-friendly treatment technologies. A need was expressed for undertaking a research project on the treatment and disposal options for waste sludge streams from colour removal treatment plants, in order to provide specific guidelines for these types of difficult to treat sludges.

Some general guidelines regarding treatment of municipal water treatment sludges are given below (Bratby, 1980), with reference to treatment and/or disposal of coloured water sludges where appropriate.

9.1 INTRODUCTION

Waste sludge from water treatment plants originate from two sources: the settling tanks underflow and the filter backwash water. The characteristics of the sludges that are produced depend largely on the type of raw water and the coagulants and flocculant aids that are used. In general, waste sludge from water treatment plants may be described as a non-Newtonian, bulky, gelatinous substance typically comprising metal hydroxide and inorganic/organic material removed from the treated water. Such sludges generally have a low solids concentration of the order 1 000 to 15 000 mg/ℓ. These concentrations are too low for convenient handling or landfill, a 20 % total solids concentration being the minimum. The sludges are also compressible so that dewatering is hampered, and of such a composition that direct disposal on land gives rise to soil clogging. Particularly problematical are sludges produced from water treatment plants using aluminium sulphate as coagulant.

The advantage of sludge dewatering prior to final disposal is that the volume of sludge is greatly reduced and handling properties improved. Once brown water sludges are dried they shrink to a small portion of the original volume and break up into small glasslike cubes which do not soften again in contact with water.

9.2 DISPOSAL OPTIONS

9.2.1 Land disposal

After thickening and dewatering the treatment plant sludge by any of the methods given in 9.3 below, the dried sludge can be disposed of in a landfill or applied to land.

9.2.2 Disposal to municipal sewer

A solution to the water treatment sludge problem in many cases is to discharge the waste stream into the domestic sewer system and thereby effectively treat the sludge at the wastewater treatment plant. With such a practice care must be taken that optimum pH conditions for biological efficiency are maintained. Apart from this, however, there does not appear to be much evidence indicating a detrimental effect on biological activity. For wastewater treatment plants with primary sedimentation the presence of a coagulated sludge may well result in decreased loads to the subsequent biological processes.

When considering direct discharge to a sewer, the following considerations are recommended (Bratby, 1980):

- amenability of the waste sludge to existing treatment processes
- hydraulic capacity of sewage treatment facilities
- the effect of the waste sludge on the final plant effluent
- cross connections must be precluded, possibly by a water break, to ensure that if the sewer backs up the raw sewage passes elsewhere
- water treatment sludge should be discharged on a continuous basis rather than as a slug flow
- the discharge of gelatinous metal hydroxide sludges may choke trickling filters, if this is the treatment process used
- possibility of silting and plugging of pipelines.

9.3 TREATMENT OPTIONS

9.3.1 Thickening

Thickening of waste sludges prior to costly dewatering processes is often a very important step in the overall disposal scheme. The volume of sludge to be subsequently dewatered is markedly reduced.

Gravity thickening, although quite widely practised, is relatively limited with water treatment plant sludges. In general, a maximum of 3 % thickened sludge concentration may be expected. The use of polyelectrolytes as sludge conditioners may slightly increase the final concentration attained.

More attractive in terms of thickening efficiency is flotation thickening. A disadvantage is that in some cases satisfactory solids recovery may not be possible without, say, polyelectrolyte conditioning. However, the much higher final concentration together with the much diminished thickener unit size is probably more than compensatory. For example, Bratby and Marais (1977) applied dissolved air flotation to thicken the sludge from a Cape water treatment plant treating brown humic coloured waters (coagulants used during treatment of the raw water were 10 mg/ℓ sodium aluminate followed by lime to adjust the pH to 5,5 after subsequent addition of 50 mg/ℓ alum). Because of the gelatinous nature of the sludge, the concentration at the bottom of the settling tanks never exceeded approximately 2 500 mg/ℓ (0,25 %). By applying dissolved air flotation to the settled sludge (in conjunction with a cationic polyelectrolyte at a dosage of 5 g/kg), float solids concentrations of up to 12 % were achieved. No Cape treatment plants employ dissolved air flotation.

9.3.2 Dewatering

Dewatering is the stage in the overall disposal strategy where the waste sludge is rendered in a handleable form for mechanical moving and trucking to ultimate disposal sites or in a form suitable for further drying.

a. Lagooning

Lagooning has been one of the most popular methods of sludge treatment due to its simplicity and low cost of operation. In areas where ample land is available, lagooning is quite economical. It is system most widely used by colour removal treatment plants in the Cape.

The general procedure in constructing a lagoon is to enclose a suitable area with dykes or excavation. Normally no attempt is made to provide additional underdrainage although artificial underdrainage would appear to present significant advantages. The method of operation is to fill the lagoon with sludge and allow it to dry whereupon more sludge is added and the process repeated until the lagoon is full of sludge dry enough for removal.

Lagooning of alum sludges may not produce a handleable end product - at times typical concentrations range from 1,5 to 2 % at the surface to of the order of 10 % at the bottom, with average concentrations of the order of 4 to 5 %. Such sludges would require further dewatering for landfill purposes.

Problems may exist with lagoons due to insect breeding and danger to children if situated in proximity to inhabitated areas. Fencing may in such cases be a necessity.

b. Drying beds

Sand drying beds, where suitable land areas are available, are used extensively for dewatering sludges. Typically they are constructed by placing a 150 to 250 mm layer of sand over an underdrainage system consisting of 300 mm graded gravel laid over drain tiles or drain pipes. Considerations in sand bed drying include the underdrainage system design; sand type and specifications; bed loading; clogging; distribution method and supernatant collection. Other parameters include air temperature and humidity; and viscosity of the sludge.

Disadvantages of drying beds are the poor dewatering obtained in cold or rainy climates; high labour costs for collection of dried sludge and hauling to disposal sites; and the long times required for adequate dewatering.

Application of alum sludges to depths 0,6 to 1,0 m requires extended drying times, sometimes in excess of 4 to 6 months before the sludge attains a concentration of, say, 20 % and may be used for landfill. However, in the choice between lagoons and drying beds, especially in cases where land costs are high, drying beds would appear to offer a more feasible solution. The inclusion of underdrains and a sand layer should not greatly add to the overall costs and dewatering should be accelerated.

c. Centrifugation

Centrifugation may be employed as a single process (without a thickening stage) to produce a product for final disposal, or it can be employed as a "thickening" device to prepare the sludge for additional dewatering. Advantages of centrifugation are the small space requirements, complete process automation and the ability to handle dilute (settled) or thickened sludge. However, although successful for lime sludges, in some cases centrifugation may not be suitable for alum sludges since final concentrations of 15 to 17 percent only are usually attainable.

Centrifuges are used for sludge treatment at the George and Faure water treatment plants in the Western Cape using ferric chloride and ferric sulphate as coagulants, respectively, and preceded by gravity thickening. Use of polyelectrolytes is essential and some method of stirring to produce a uniform feed sludge is highly desirable.

d. Filter presses

Pressure filtration is essentially a batch process in which preconditioned sludge is pumped into cloth lined spaces retained between a series of substantial plates. Sludge is introduced through holes in the centre of the plates into the space between the filter cloths at a pressure of 400 - 650 kPa. Filtrate is forced through the cloths and the retained solids form a cake. Discharge of the pressed cake can be manually or automatically controlled by releasing pressure and separating the plates.

With polyelectrolyte conditioning and after thickening to 1,5 to 2 % solids, filter cake concentrations of 15 to 20 % solids are attainable with alum sludges.

Two disadvantages are associated with filter presses: the first is the short life of the filter cloths and the second the lack of automation. However, they have often been the dewatering facility chosen due not only to the high cake solids concentrations attainable, but also the lower general operating costs.

e. Belt filter press

The belt filter press has been under development for many years and numerous variations have been evolved by machinery suppliers. They all consist of a horizontal woven belt on which the conditioned sludge is fed and a press belt which bears on the other, the belt being kept in contact by a series of individually adjustable rollers.

Using alum sludges (of approximately 2,5 % feed concentration) preconditioned with 5 to 7 g/kg polyelectrolyte, filter cake concentrations of 8 to 12 % have been reported (Bratby, 1980) with filtrate concentrations of 25 to 60 mg/ℓ.

f. Vacuum filtration

Although favourable results have been reported for dewatering of lime sludges, this is not always the case, especially with alum sludges. Furthermore, since dewatering of dilute sludges (*i.e.* without prior thickening) is precluded with vacuum filtration, vacuum filtration of alum sludges may be economically and technologically unfeasible and other methods may be preferable. No Cape treatment plants employ this process.

g. Thermal conditioning

Heat treatment of sludge under pressure (175 to 200 °C at 1200 to 1400 kPa) results in the breakdown of the gelatinous flocs of alum sludges and an increased rate of dewatering. Freezing has a similar effect.

Disadvantages of these heat treatment processes are the considerable energy input to achieve the necessary temperatures, and the maintenance requirements of pumps and the "shell and tube" heat exchangers are high and represent a significant operating cost.

9.4 COAGULANT RECOVERY FROM SLUDGE

A process of recovering coagulant for reuse may be feasible in terms of minimizing sludge disposal costs. In the case of alum sludges, the recovery process is accomplished essentially in three steps (Abdo *et al*, 1993):

(1) thickening of the waste sludge to minimise volumes and to ensure a sufficiently high concentration of recovered alum (at leat 2 %)
(2) acidification of the thickened sludge with sulphuric acid to produce aluminium sulphate
(3) separation of undesirable suspended matter from the alum solution.

In the acidification step, acid is required in excess of that for reaction with aluminium to ensure a low pH (≈ 2,0). Low pH values improve the settling and filtering characteristics of the solid matter that must be removed to produce an alum solution suitable for reuse. Separation of the undesirable suspended matter may be accomplished either by settling out the solids in a basin or by removing the solids with a filter press. In settling, the recovered alum is the overflow and the solid residue is removed from the basin via the underflow. The underflow solids are usually mixed with lime for pH neutralization and conditioning prior to dewatering by vacuum filtration, pressure filtration or other suitable means.

In some cases the underflow is passed directly to a dewatering facility. This has the advantage of improving the percentage of recovered alum and reducing the subsequent lime dosage necessary to neutralize the waste sludge prior to disposal. With this procedure, and using filter presses, cake solids concentrations have been reported to be of the order of 40 to 55 %. The recovery of reusable alum is of the order of 50 to 75 %.

Advantages of acid treatment are that acidified sludge dewaters at a faster rate (since aluminium hydroxide has been dissolved) and the final volume for disposal is lower due to removal of the aluminium hydroxide fraction.

However, the alum recovery process is not widely used principally because of the relatively poor efficiency of recovery and the progressively poorer quality of alum recovered.

In coloured water treatment plants, excessive build-up of acid soluble impurities such as organic colour compounds, iron and manganese may occur, leading to poor quality of alum recovered and deterioration of final water quality. The recovery process is therefore generally not suitable for colour removal treatment plants.

The process may, however, be economical for colour removal treatment plants where the recovered alum can be used at a wastewater treatment plant for phosphorous precipitation. In this case the impurities in the recovered alum will not be a disadvantage. Advantages would be, apart from phosphorous precipitation, improved COD and solids removal during primary sedimentation.

In cases where the cost of recovered alum is higher than the cost of the virgin alum itself, the advantages of improved sludge dewatering characteristics may not compensate the cost of acid treatment. Furthermore, in the smaller plants, the degree of skilled operator control required for the process may preclude consideration.

CHAPTER 10

GUIDELINES FOR THE TREATMENT OF COLOURED WATER

10.1 CRITERIA FOR THE SELECTION OF MOST SUITABLE TREATMENT CONFIGURATIONS AND UNIT TREATMENT PROCESSES

In planning a new water treatment works to treat a coloured water, the factors to be considered are: the character of the raw water source; the cost of the appropriate treatment alternatives (both capital and operating costs); and aspects related to the eventual operation of the plant, *i.e.* ease of operation, operational control and maintenance requirements. These criteria are discussed in more detail below.

a. Character of raw water

It is essential to characterize the raw water source to ensure that the selection of unit treatment processes represents the most cost-efficient way of producing an acceptable and safe drinking water.

Because the quality of coloured raw waters can vary considerably in time and location, samples of the source should be taken over a period of time at the point where it is to be abstracted, preferably for at least a year to include seasonal variations. The samples should be analysed for the following quality parameters:

Apparent colour
True colour
UV Absorbance and/or dissolved organic carbon (DOC)

Turbidity
pH
Conductivity
Alkalinity and acidity
Calcium
Magnesium
Iron
Manganese
Aluminium
Samples from coagulation tests

It is proposed that the procedures for doing the above physical and chemical analyses be standardized for the characterisation of organically coloured water sources in South Africa. The proposed standard procedures for these determinations are given in Annexure D.

b. Cost considerations

In the selection of a suitable treatment process both the cost of construction and the expected operating costs plays important roles. This is especially important for the smaller water suppliers who can not afford expensive treatment systems with high running costs. However, sometimes economics in capital works result in very high running costs and inadequate treatment. A poorly designed plant will require more staff to operate properly.

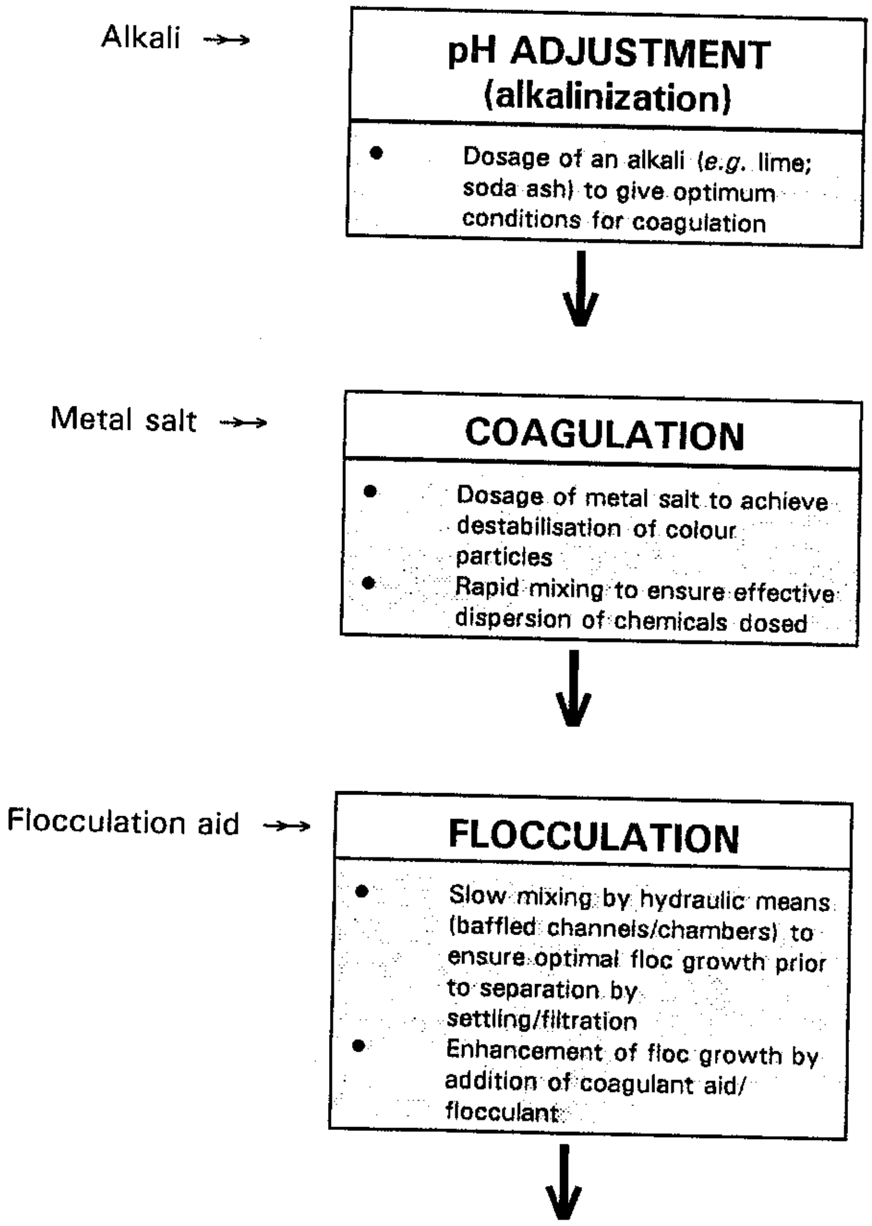
c. Operational aspects

The operational aspects include the ease of operation (*i.e.* specific skills required by process controllers, degree of automation, chemical handling, access to equipment and instrumentation, availability of chemicals and spares) and maintenance requirements (mechanical content, sophistication and durability of the plant and its components). All of these aspects have a direct influence on the number and quality of personnel required to operate the plant in a cost-effective manner. The operational aspects are discussed in Chapter 7.

10.2 SUMMARY OF CHEMICAL PRECIPITATION AND PHASE SEPARATION PROCESSES FOR THE TREATMENT OF COLOURED WATER

The unit process and process configurations that are currently used for the treatment of coloured water, or which have been evaluated for the removal of organic colour, are summarised schematically below.

10.2.1 Conventional treatment



Alkali →→

pH ADJUSTMENT (alkalinization)

- Dosage of an alkali (*e.g.* lime; soda ash) to give optimum conditions for coagulation

Metal salt →→

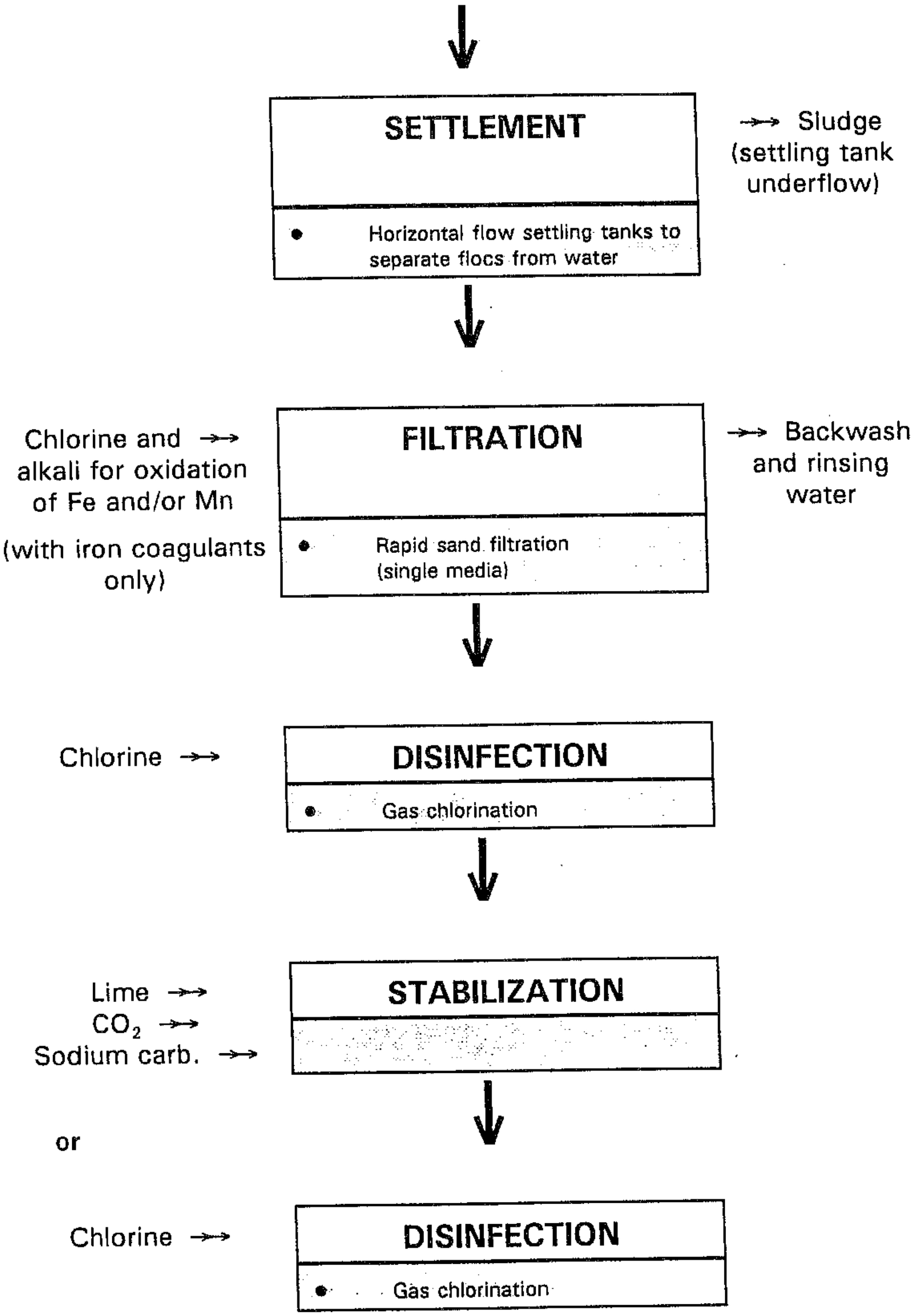
COAGULATION

- Dosage of metal salt to achieve destabilisation of colour particles
- Rapid mixing to ensure effective dispersion of chemicals dosed

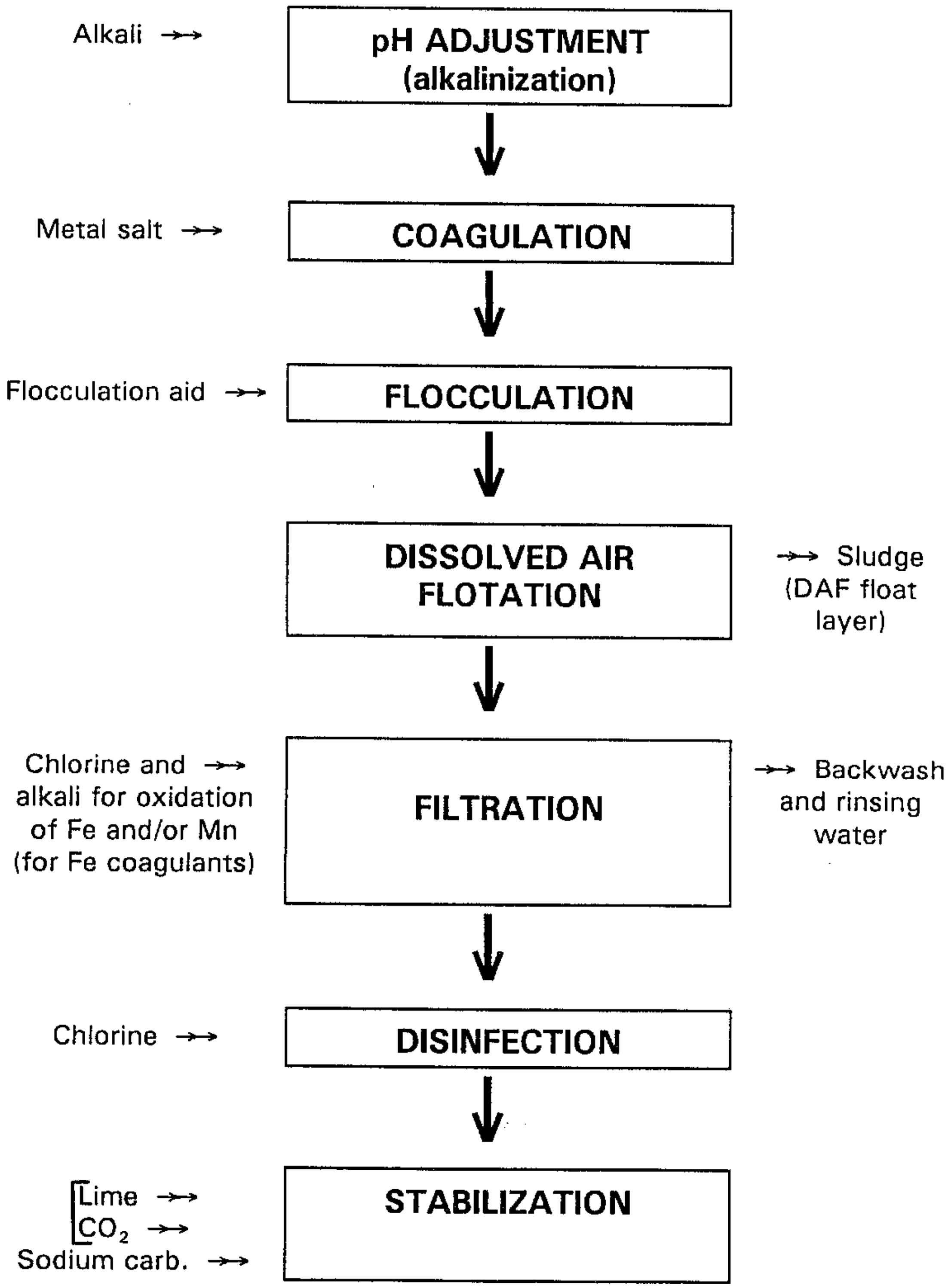
Flocculation aid →→

FLOCCULATION

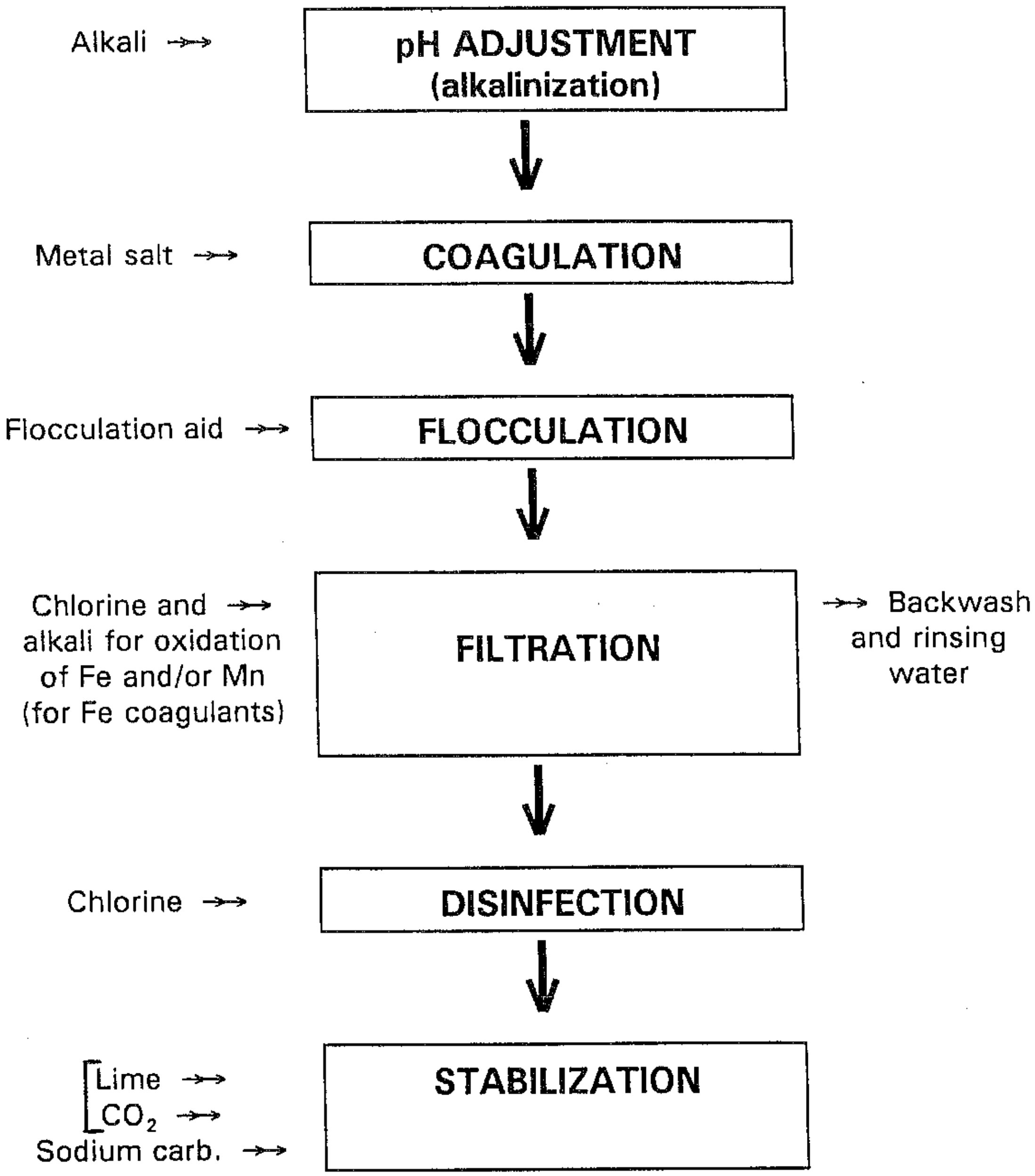
- Slow mixing by hydraulic means (baffled channels/chambers) to ensure optimal floc growth prior to separation by settling/filtration
- Enhancement of floc growth by addition of coagulant aid/ flocculant


SETTLEMENT
Horizontal flow settling tanks to separate flocs from water
Sludge (settling tank underflow)
Chlorine and alkali for oxidation of Fe and/or Mn
(with iron coagulants only)
FILTRATION
Rapid sand filtration (single media)
Backwash and rinsing water
Chlorine
DISINFECTION
Gas chlorination
Lime
CO_2
Sodium carb.
STABILIZATION
or
Chlorine
DISINFECTION
Gas chlorination

10.2.2 Dissolved air flotation



10.2.3 Direct filtration



10.3 GUIDELINES FOR DESIGN AND OPERATION OF PROCESSES USED IN COLOURED WATER TREATMENT PLANTS

10.3.1 Coagulation

a. Rapid mixing

- Plug-flow mixers have been found to be the most effective for the treatment of Cape coloured waters. These systems are (*cf. Figure 6.2*):

  - overflow weir (hydraulic jump)
  - baffled mixing race
  - orifice plate in a pipe

- Velocity gradients (G values) required for plug-flow rapid mixing units are in the range of 1 200 to 2 500 s^{-1}.

- There should be a gradual decrease in velocity gradient from the rapid mixing stage to the flocculation stage.

- For coagulation of colour causing substances, rapid mixing should be done in as short a time as possible. However, to determine a suitable rapid mix period for a specific water, laboratory scale and/or pilot scale studies need to be conducted using that particular water.

b. Coagulants

- Primary coagulants that can be used for colour removal are mainly the traditional metal salts used for particle destabilisation, *i.e.* aluminium sulphate (alum), ferric sulphate and ferric chloride. The selection of which primary coagulant to use at a particular colour removal treatment plant depends on a number of factors, *viz.* raw water quality (pH, alkalinity, colour, metals), sophistication of the plant in terms of process control and monitoring, materials of construction and of dosing equipment used at the plant, options available for sludge disposal, availability of supply of the coagulants to the plant, and to a lesser extent, the cost of the coagulant. A comparison of these three primary coagulants based on these factors are given in Table 6.1.

Polyaluminium chloride (PACℓ) blends are also used as primary coagulant for colour removal in certain treatment plants. The advantage of using this primary coagulant-polyelectrolyte blend is that in most cases no pH adjustment is required in the coagulation step when using PACℓ; however, it is not efficient for colour removal in waters with medium to high colour concentrations, and its relative high cost normally restricts its application to smaller treatment plants.

Sodium aluminate can be used together with alum as an aid for quicker floc formation by effectively raising the pH in the coagulation process and requiring less lime to be dosed to achieve the optimum pH range for alum. However, sodium aluminate is not produced locally and it should be established beforehand whether its use would be cost-efficient for a certain application.

- Sodium aluminate can be used in conjunction with the above primary coagulants to obtain more rapid floc formation.

- Coagulant feed concentrations of 0,5 % have been found to be optimal for good stabilization of particles.

- Polyelectrolytes can be used as coagulant aids to assist with coagulation and floc formation, but are not effective as primary coagulant on its own for treatment of coloured water by the conventional processes of coagulation, settling and filtration.

c. <u>Coagulant dosage and dosage control</u>

- See Section 7.2.1

d. <u>pH adjustment in the coagulation process</u>

- For optimum removal of colour causing substances (humic material) by chemical coagulation, the coagulation pH should be maintained at the following values:

  - <u>alum</u>
    The optimum pH lies in the range 5,0 - 6,0. To minimize aluminium levels in the final water from the plant, it is recommended that the coagulation pH not be lower than 5,8; however, in plants treating highly coloured water, the colour removal efficiency rapidly deteriorates at these pH levels, and lower pH levels (5,0 - 5,5) are mostly maintained. In this case, the pH must then be increased ahead of filtration to remove most of the residual aluminium in the sand filters.

  - <u>ferric sulphate</u>
    The optimum pH lies in the range 3,8 - 5,0. For highly coloured waters, the optimum pH would lie at the lower pH levels, while for lower colour levels, the optimum coagulation pH would be higher.

    When using a ferric salt, the pH must be increased to at least 7,5 ahead of the sand filters to remove the dissolved iron remaining after the settling process.

  - <u>ferric chloride</u>
    The optimum pH lies in the range 3,7 - 4,8. For highly coloured waters, the optimum pH would also lie at the lower pH levels (the same as with ferric sulphate), while for lower colour levels, the optimum coagulation pH would be higher.

    The pH must also be increased to at least 7,5 ahead of the sand filters when using ferric chloride, to remove the dissolved iron remaining after the settling process.

e. **pH adjustment chemicals**

- Lime or sodium carbonate (soda-ash) are most widely used for adjusting the pH to the required optimum ranges, as given above. When using alum as coagulant, sodium carbonate or a good quality lime should be used, because the pH level of 9,0 and higher which is required to precipitate the manganese in brown lime on the filters will redissolve the aluminium and result in high aluminium levels in the final water.

- Problems are often experienced with dosing dry lime powder, mainly with blockages in the dry lime feeder and dosing equipment. However, systems have been developed locally which are giving good service at a number of treatment plants in the Southern Cape where they have been installed in the last number of years.

10.3.2 Flocculation

a. **Flocculation systems**

- The most frequently used flocculation systems in plants treating coloured water are baffled flocculation chambers or channels (vertical plates), where the head loss through the chamber/channel provides the mixing energy.

  These flocculation channels are shown in Figure 6.3.

- The recommended flocculation system design criteria are as follows:

-	velocity gradient (G):	45 - 90 s^{-1}
-	retention time (t):	30 minutes
-	GT value:	80 000 - 160 000

- For each individual flocculator, the optimal GT value should be carefully selected, and taken as high as is consistent with the optimal formation of flocs without causing disruption or disintegration of the flocs after they have formed.

b. <u>**Flocculation aids (coagulation aids)**</u>

- Because of the lightness of the flocs that are formed in the coagulation of colour causing substances, flocculation aids are often dosed in the flocculation channel to give more weight to the flocs or increase their size, and thereby enhance removal. These flocculants can be polyelectrolytes (normally high molecular weight cationic types), clay (bentonite) and activated silica.

10.3.3 Settlement

- Because of the lightness and fragility of the flocs that are formed during coagulation in colour removal treatment plants, horizontal settling tanks have been found to give the best quality settled water (lowest turbidities).

- Horizontal settling tanks with high length:width ratios (*i.e. long tanks* like that at the Blackheath and Faure treatment plants) have been found to produce substantially better removal of flocs than those with lower length:width ratios (*i.e. more square tanks* such as those used at the smaller treatment plants in the Southern Cape).

- The inlet and outlet arrangements to and from the horizontal settling tanks are very important in ensuring good settling. There must be a gradual reduction in velocity gradient from the flocculation channels to the quiescent flow conditions in the settling tank. (*See Figure 6.4*)

- Covering of settling tanks provides better settling by reducing the effect of lifting of flocs (and subsequent floc carry-over) by direct sunlight or by strong wind. Covering can be with asbestos sheeting or with black shade nets.

- Because of the aggressive attack on concrete in the settling tanks by the soft acidic waters (especially in plants treating highly coloured waters where low coagulation pH provides optimum colour removal), these concrete surfaces should be protected with a bitumen coating.

10.3.4 Dissolved air flotation

- While effective removal of organic colour can be achieved by dissolved air flotation, further development of the process is required to stabilize the sludge float that is formed on the surface of the clarification zone to prevent flocs settling to the bottom, and thereby ensuring consistent DAF performance.

- An 8 % recycle ratio was found to be sufficient for good colour removal with DAF.

10.3.5 Filtration

a. <u>Rapid sand filtration</u>

- A single, homogeneous layer of sand has been found to produce the best results (filtrate quality; length of filter run) when treating coloured water.

- The best filter underdrain system is a false filter floor with nozzles.

- Backwashing with simultaneous air scour and filtered water has been found to provide the best cleaning of the filter bed by not stratifying the bed during cleaning.

- While the backwashing frequency can be optimised, it is general practice at most of the treatment plants treating Cape coloured water to backwash their filters on a routine basis, thereby allowing a safety margin to prevent break-through or at the large plants, to avoid congestion when more than one filter needs to be backwashed at the same time.

  The larger quantities of backwash water and higher energy input needed when backwashing on a routine basis can be justified when the backwash water is recycled and/or if the plant generates its own electricity.

b. **Direct filtration**

- Direct filtration is only suitable for treatment of raw waters with low to moderate colour levels (up to 80 mg/ℓ as Pt).

- Better removal of TOC and THM precursors have been found when using alum than when using polyelectrolytes with direct filtration.

- Polyelectrolytes may be efficient for treating waters with low to moderate colour, but the polyelectrolyte dosages would be too high and costly, and the quality of the treated water would not be satisfactory in terms of TOC and THM precursors.

10.3.6 Disinfection

a. **Chlorination**

- The minimum chlorine contact period should be 10 to 15 minutes, but should preferably be several hours because the shorter the contact time, the higher the chlorine dosage will be to provide a sufficient free chlorine residual that is required for effective disinfection.

- The free chlorine residual at the end of the contact period should be 0,5 to 1,0 mg/ℓ as $C\ell_2$. In distribution networks with long residence times, it may be necessary to rechlorinate at certain points (normally at reservoirs) to provide a sufficient free chlorine residual at the furthest points in the network.

- The sand filtration process should produce a high quality filtered water to ensure that subsequent chlorination will be effective. Turbidity levels must be less than 1,0 NTU (but preferably even considerably lower) to ensure that suspended matter does not envelop bacteria and shield them from attack by chlorine. Similarly, if iron and manganese is not removed effectively before final chlorination, it will exercise a chlorine demand, resulting in lower free chlorine residuals in the final water.

- Waters with low alkalinity and pH values below 7,2 are disinfected more readily than waters with high pH values. For coloured waters, more effective disinfection will thus be obtained by chlorinating primarily ahead of the sand filters and applying final chlorination to the filtered water. Chlorinating before filtration will also ensure that the filter media are kept free from biological and that metals (iron and manganese) will be precipitated (if the pH is raised to appropriate levels).

- When using chlorine as means of disinfection of coloured waters, it is important to ensure that the organic substances in the water that results in the formation of disinfection by-products (notably THMs), be removed effectively before chlorination is applied. This can be accomplished by using enhanced coagulation, activated carbon adsorption and/or membrane processes. A new WRC project to investigate the chemical removal of organic substances in South African coloured surface waters has recently commenced, and will in particular address the need for enhanced coagulation to minimise THM formation potential.

b. <u>Other means of disinfection</u>

- Ozone is used in several European countries for disinfection of final treated water. In South Africa it has up to now been considered a too expensive and sophisticated disinfection option, but has recently been receiving renewed interest.

- Ultraviolet radiation (UV) may also be used to disinfect the final water from a water purification plant. However, to be cost-efficient as disinfection method, the filtered water must be of a high quality with high clarity, and should not contain any dissolved metals that will absorb the ultraviolet light rays. This method of disinfection have been used successfully at small treatment plants, and is also receiving interest in possible application at larger plants locally.

10.3.7 Stabilization

- See Section 6.3 for full details on stabilization and Section 7.2.4 for stabilization control.

10.4 LIST OF PROBLEMS WITH TREATMENT OF COLOURED WATER AND SPECIFIC GUIDELINES FOR SOLVING OR REMEDYING THEM

PROBLEMS (Potential)	GUIDELINE (Measure/ Remedy)
Colour in final water as a result of inadequate dosage control	● Measure raw water colour ● Determine coagulant dosage from dosage curve ● Maintain coagulation pH at optimum value: Alum high colour 5,0 - 5,5 low colour 5,7 - 6,5 $Fe_2(SO_4)_3$ 4,0 - 5,0 $FeCl_3$ 4,0 - 5,0
Overdosing of coagulant in an attempt to improve poor colour removal	● Measure raw water colour ● Determine coagulant dosage from dosage curve ● Maintain coagulation pH at optimum value: Alum high colour 5,0 - 5,5 low colour 5,7 - 6,5 $Fe_2(SO_4)_3$ 4,0 - 5,0 $FeCl_3$ 4,0 - 5,0
High aluminium residual in final water	● Coagulate in pH range which will result in minimum aluminium residual, *i.e.* pH of 5,7 - 6,5, or raise pH before filtration if flocculating at lower pH

PROBLEMS (Potential)	**GUIDELINE** (Measure/ Remedy)
Floc carry-over and break-up because of lightness and fragility of humic flocs	• Dose suitable coagulant aid or weighting agent (determine type with beaker tests)
Floc lifting and carry-over in settling tanks due to wind action and uneven heating	• Cover settling tanks with suitable roof covering (fibre cement or netting)
Iron and manganese in final water to the consumer	• Check settlement and filtration • Oxidise iron and/or manganese by chemical means ahead of sand filters (only when using Fe coagulants)
Biological growth in settling tanks and filters	• Chlorinate 1 mg/ℓ ahead of filters
THM formation when waters with residual organic material are chlorinated	• Improve removal of THM precursors before chlorination • Use alternative disinfectants (although these can produce other undesirable disinfection by-products [DBPs])
Colour in water at consumer taps when certain types of soap or detergent are used	• Remove iron, manganese and aluminium to recommended limits at the treatment works • Stabilize before filtration • Control stabilization process (as given in Chapter 7)
Inaccurate or inadequate pH measurement	• Measure pH according to proposed standard procedure • Operate and maintain equipment as prescribed
Production of large volumes of sludge with poor dewatering characteristics	• Select suitable method for sludge treatment and disposal (see Chapter 9)(however, further research needed)

PROBLEMS (Potential)	**GUIDELINE** (Measure/ Remedy)
Problems with lime dosing because of inconsistent quality of lime supply	● Select best quality lime by regular testing of products supplied
Aggression and corrosion of storage systems and network as a result of ineffective stabilization	● Perform stabilization according to guidelines in Section 6.3
Deposits in pipes due to overstabilization	● Employ regular and accurate monitoring and control of final pH and alkalinity

CHAPTER 11

CONCLUSIONS AND RECOMMENDATIONS

While the project has achieved its aim of providing practical and useful guidelines especially to plant operating personnel, it's extent did not allow any in-depth investigation of the chemical treatability of the South African coloured waters by coagulation. At the last Steering Committee Meeting of this project, the Steering Committee indicated that it was necessary to undertake further research on the treatability of the various types of coloured waters that are encountered in the country, with specific emphasis on characterisation of the organic matter in these waters and assessment of its removal by chemical coagulation.

To transfer the results of the guidelines project to the end user, a seminar/workshop (jointly organised by the WRC) was held in Mossel Bay in October 1996 to obtain inputs from all institutions/persons involved in the treatment of coloured water (design engineers; water suppliers; operating personnel; researchers; chemical and equipment suppliers) before finalizing the guidelines document for distribution. During the workshop, at which most of the role players in the treatment of coloured water in South Africa were present, the WRC also facilitated a session to identify research needs in the treatment of coloured waters, and to prioritise these needs as far as possible.

By far the highest priority for further research was found to be the need for characterisation and removal of unwanted organic compounds in coloured waters. Little information is available on the true character and properties of the local coloured waters, and more specifically on its high variability in locality and time, as well as the many complexes that are formed with other substances, notably metals. There is also a lack of knowledge on the effect of treatment processes, in particular coagulation, on the removal of the different constituents of the coloured water. The investigation of existing treatment practices to draw up the guidelines document only entailed once-off basic determination of raw water quality at the plants that were visited, and did not allow any detailed characterisation of the natural organic matter or its spatial or seasonal-variation. Treatability studies were also limited to standard beaker tests for determining or confirming optimum coagulant dosages and pH for colour removal and minimising metal residuals in the final water. There is, therefore, a need for a more fundamental characterisation of natural organic matter in South African coloured waters and classifying the coloured surface water sources, and to use this for establishing the treatability of the different classes of coloured water. This need for further research on organic matter and colour removal was also confirmed at a Technology Transfer Fair on Drinking Water Treatment that was presented by the WRC in Johannesburg during November 1996.

Considerable work on the characterisation of organic matter in coloured waters has been done overseas, notably in the UK (WRc; Severn Trent Water), USA (AWWA Research Foundation), Australia (Australian Water Quality Centre, CSIRO and Monash University) and Norway (Norwegian Institute of Water Research). These included land use (catchment studies), colour and natural organic matter (NOM) characterisation, bench-scale treatability studies (batch tests) and continuous flow studies. A study at the University of Cape Town (Gardiner, 1988) has, however, shown that South African coloured waters have considerably higher colour levels than in these countries, and that especially in standing waters (such as dams and lakelets) the colour intensity is very high by international standards. The results of the NOM characterisation performed overseas can hence not be applied directly to local waters to assess its treatability by existing processes or new processes that are being developed.

A number of local universities and institutions are currently performing (or have recently completed) research projects on the application and/or development of new treatment processes for colour removal (Van der Walt and Pearson, 1996; Juby and Botha, 1994; Jacobs et al; 1996; Cloete et al, 1996; Loewenthal, 1997). The results of a characterisation and classification study would also be of value to these research groups in determining process applicability and treatment strategies, and further process development.

A follow-up project has commenced, to characterize South African coloured surface waters and investigate their treatability by the coagulation process.

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ANNEXURE A

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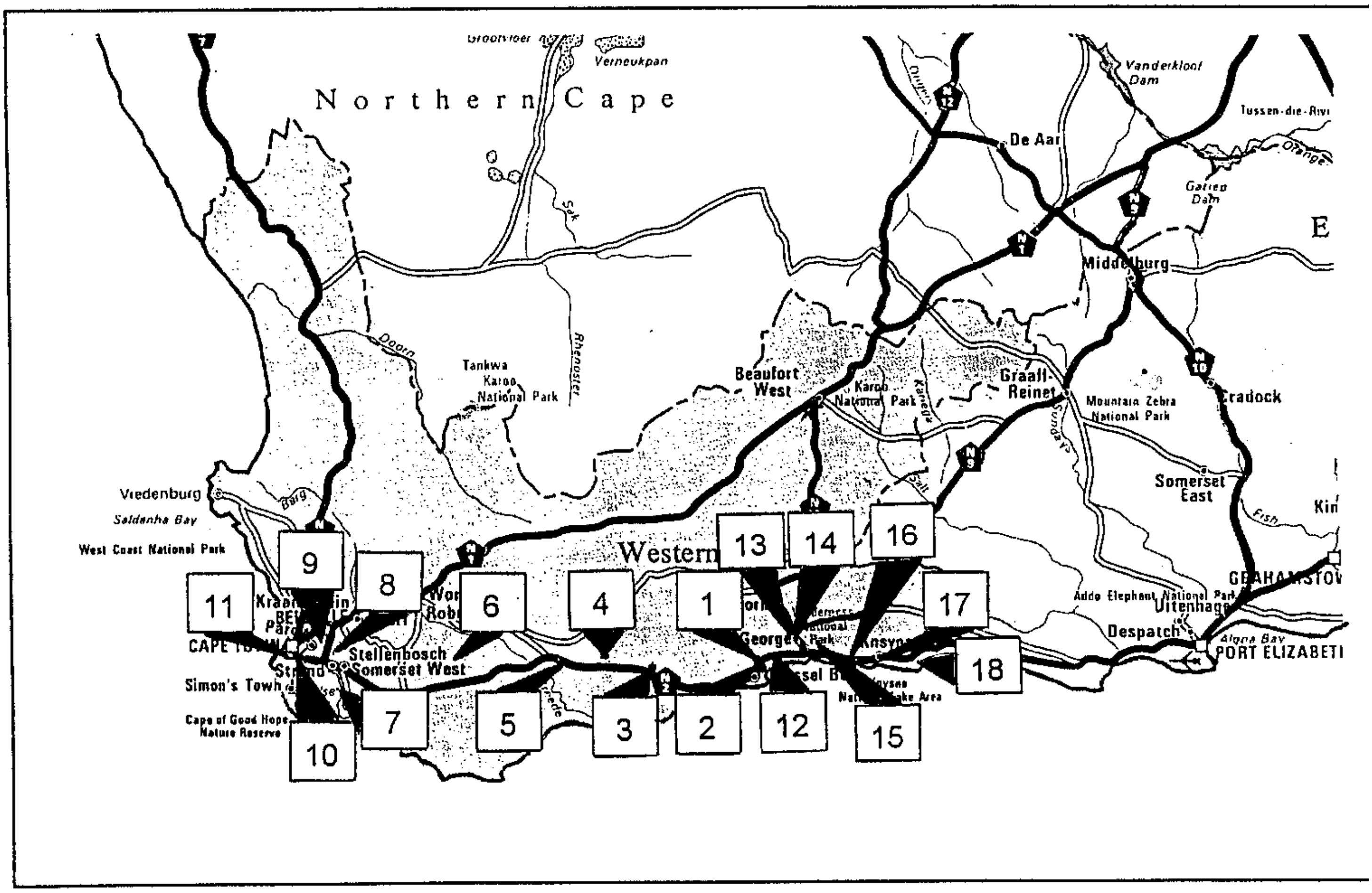
ANNEXURE B

DETAILS OF TREATMENT PLANTS SURVEYED



1. Sandhoogte
2. Kleinbrak
3. Riversdale
4. Duivenhoks
5. Swellendam
6. Rûensveld Wes
7. Steenbras
8. Faure
9. Blackheath
10. Constantia Nek
11. Kloofnek
12. Grootbrak
13. George Old
14. George New
15. Wilderness
16. Sedgefield
17. Knysna
18. Plettenberg Bay

LOCATION OF PLANTS THAT WERE SURVEYED IN THE WESTERN AND SOUTHERN CAPE

SANDHOOGTE
Mossel Bay Municipality

DESIGN CAPACITY OF THE PLANT: 5,0 Mℓ/day

RAW WATER QUALITY (Range)

Colour (apparent) (mg/ℓ as Pt)	366 - 960	pH	3,24 - 5,30
Colour (true) (mg/ℓ as Pt)	150 - 886	T Alkalinity (mg/ℓ as $CaCO_3$)	0 - 0,8
UV abs. @ 254nm. (4 cm)	2,38 - 4,33	Calcium (mg/ℓ as Ca)	1,6 - 25
Diss. organic carbon (mg/ℓ)	8,0 - 25	Magnesium (mg/ℓ as Mg)	1,0 - 4,1
Turbidity (NTU)	0,5 - 2,2	T Hardness (mg/ℓ as $CaCO_3$)	8 - 80
Conductivity (mS/m)	5 - 14	Sulphate (mg/ℓ as SO_4)	
Chloride (mg/ℓ as Cl)	5 - 103	Iron (mg/ℓ as Fe)	0,30 - 0,85
Sodium (mg/ℓ as Na)		Manganese (mg/ℓ as Mn)	0 - 0,18
Potassium (mg/ℓ as K)		Aluminium (mg/ℓ as Al)	0,58 - 0,89

TREATMENT PROCESSES

pH adjustment	- Lime - Typical dosage: 50 - 90 mg/ℓ - Dosed before ferric sulphate
Coagulation	- Ferric sulphate at pH 4,4 - Typical dosage: 90 mg/ℓ as ferric sulphate - Rapid mixing in mixing race
Flocculation	- Hydraulic in flocculation channels
Settling	- 2 x horizontal flow settling tanks - Retention time: 2 hours - Settling tanks covered with asbestos plates
Additional chemicals	- None
Filtration	- 3 x rapid sand filters (2 x multimedia; 1 x single medium)(later changed to 3 x single medium) - Backwash daily (routine)
Disinfection	- Chlorination with gaseous chlorine - Maintain free chlorine residual of 0,5 mg/ℓ - Chlorine dosed after lime for stabilisation
Stabilization	- Lime - Aim at final pH of 9,2

KLEINBRAK
Mossel Bay Municipality

DESIGN CAPACITY OF THE PLANT: **22,0** **Mℓ/day**

RAW WATER QUALITY (Range)

Colour (apparent) (mg/ℓ as Pt)	322 - 770	pH	3,75 - 7,70
Colour (true) (mg/ℓ as Pt)	45 - 487	T Alkalinity (mg/ℓ as $CaCO_3$)	0 - 52
UV absorbance		Calcium (mg/ℓ as Ca)	4 - 32
Diss. organic carbon (mg/ℓ)		Magnesium (mg/ℓ as Mg)	1,7 - 16,5
Turbidity (NTU)	6,9 - 45	T Hardness (mg/ℓ as $CaCO_3$)	18 - 150
Conductivity (mS/m)	7 - 55	Sulphate (mg/ℓ as SO_4)	
Chloride (mg/ℓ as Cl)	25 - 179	Iron (mg/ℓ as Fe)	0 - 9,2
Sodium (mg/ℓ as Na)		Manganese (mg/ℓ as Mn)	0 - 0,76
Potassium (mg/ℓ as K)		Aluminium (mg/ℓ as Al)	0,37 - 3,8

TREATMENT PROCESSES

pH adjustment	- Lime - Dosed before ferric chloride
Coagulation	- Alum (later changed to ferric chloride) - Typical dosage: Alum 70 mg/ℓ; $FeCl_3$ 50 mg/ℓ - Mixing in-line with orifice plates
Flocculation	- Cationic polyelectrolyte on occasion for turbidity removal and enhanced colour removal - Flocculation channel
Settling	- 4 x horizontal flow settling tanks - Covered with asbestos sheets
Additional chemicals	- None
Filtration	- 8 x rapid sand filters (single medium)
Disinfection	- Chlorination with gaseous chlorine - Maintain free chlorine residual of 0,5 mg/ℓ - Chlorine dosed after lime for stabilisation
Stabilization	- Lime - Aim at pH of 9,0-9,2

RIVERSDALE
Riversdale Municipality

DESIGN CAPACITY OF THE PLANT:	2,8	Mℓ/day

RAW WATER QUALITY (Typical)			
Colour (apparent) (mg/ℓ as Pt)	300	pH	5,8
Colour (true) (mg/ℓ as Pt)	240	T Alkalinity (mg/ℓ as $CaCO_3$)	3,3
UV absorbance		Calcium (mg/ℓ as Ca)	
Diss. organic carbon (mg/ℓ)	9,9	Magnesium (mg/ℓ as Mg)	
Turbidity (NTU)	5,0	T Hardness (mg/ℓ as $CaCO_3$)	18
Conductivity (mS/m)		Sulphate (mg/ℓ as SO_4)	
Chloride (mg/ℓ as Cl)		Iron (mg/ℓ as Fe)	
Sodium (mg/ℓ as Na)		Manganese (mg/ℓ as Mn)	
Potassium (mg/ℓ as K)		Aluminium (mg/ℓ as Al)	

TREATMENT PROCESSES	
pH adjustment	- Soda-ash - Typical dosage: 50 mg/ℓ - Dosed after alum in the mixing race
Coagulation	- Alum - Typical dosage: 50 mg/ℓ - Rapid mixing with hydraulic jump
Flocculation	- Hydraulic in concrete channels with baffles
Settling	- 1 x horizontal flow settling tank
Additional chemicals	- None
Filtration	- 3 x rapid sand filters - Backwash 1 to 3 times per week (routine)
Disinfection	- Chlorination with gaseous chlorine - Maintain free chlorine residual of 0,3 mg/ℓ - Chlorine dosed after lime for stabilisation
Stabilization	- Lime - Typical dosage: 25 mg/ℓ - Maintain final pH at 9,0

DUIVENHOKS
Overberg Water

DESIGN CAPACITY OF THE PLANT: 5,0 Mℓ/day

RAW WATER QUALITY (Range)			
Colour (apparent) (mg/ℓ as Pt)	160 - 650	pH	4,1 - 6,5
Colour (true) (mg/ℓ as Pt)		T Alkalinity (mg/ℓ as $CaCO_3$)	2 - 28
UV absorbance		Calcium (mg/ℓ as Ca)	4 - 30
Diss. organic carbon (mg/ℓ)		Magnesium (mg/ℓ as Mg)	1,0 - 8,3
Turbidity (NTU)	2 - 400	T Hardness (mg/ℓ as $CaCO_3$)	8 - 64
Conductivity (mS/m)	8 - 70	Sulphate (mg/ℓ as SO_4)	
Chloride (mg/ℓ as Cl)	20 - 94	Iron (mg/ℓ as Fe)	0,46 - 1,42
Sodium (mg/ℓ as Na)		Manganese (mg/ℓ as Mn)	0,07 - 0,13
Temperature (°C)	7 - 26	Aluminium (mg/ℓ as Al)	0,04 - 0,16

TREATMENT PROCESSES	
pH adjustment	- Lime - Typical dosage: 50 mg/ℓ - Dosed before alum in the mixing race
Coagulation	- Alum - Typical dosage: 70 mg/ℓ - Rapid mixing in-line with orifice mixer
Flocculation	- Hydraulic in concrete channels
Settling	- Horizontal flow settling tanks - Retention time: 6 - 10 hours
Additional chemicals	- Bentonite: approx. 10 mg/ℓ to give weight to flocs for improved settling
Filtration	- Rapid sand filters - Average filter runs: 60 hours
Disinfection	- Chlorination with gaseous chlorine - Typical dosage: 1,8 - 2,0 mg/ℓ - Chlorine dosed before lime for stabilisation
Stabilization	- Lime - Aim at alkalinity of 34 mg/ℓ as $CaCO_3$ - Decrease pH with CO_2 to 9,0

SWELLENDAM
Swellendam Municipality

DESIGN CAPACITY OF THE PLANT: 2,0 Mℓ/day

RAW WATER QUALITY (Typical)

Colour (apparent) (mg/ℓ as Pt)	160	pH	5,8
Colour (true) (mg/ℓ as Pt)	100	T Alkalinity (mg/ℓ as $CaCO_3$)	3,0
UV absorbance		Calcium (mg/ℓ as Ca)	
Diss. organic carbon (mg/ℓ)	6,6	Magnesium (mg/ℓ as Mg)	
Turbidity (NTU)	8,5	T Hardness (mg/ℓ as $CaCO_3$)	10
Conductivity (mS/m)		Sulphate (mg/ℓ as SO_4)	
Chloride (mg/ℓ as Cl)		Iron (mg/ℓ as Fe)	1,36
Sodium (mg/ℓ as Na)		Manganese (mg/ℓ as Mn)	
Potassium (mg/ℓ as K)		Aluminium (mg/ℓ as Al)	

TREATMENT PROCESSES

pH adjustment	- Lime - Typical dosage: 25 mg/ℓ - Dosed after alum in the mixing race
Coagulation	- Alum - Typical dosage: 40 mg/ℓ - Rapid mixing in mixing race
Flocculation	- Hydraulic in concrete channels with baffles
Settling	- 6 x horizontal flow settling tanks - Retention time: 4 hours
Additional chemicals	- None
Filtration	- 11 x slow sand filters (1,0 m gravel, 0,5 m sand) - *Schmutzdecke* replaced every 7 to 8 weeks - 4 x pressure sand filters
Disinfection	- Chlorine with gaseous chlorine - Maintain free chlorine residual of 0,8 mg/ℓ - Chlorine dosed after lime for stabilisation
Stabilization	- Soda-ash - Maintain final pH at 8,7 - 9,0

RÛENSVELD WES
Overberg Water

DESIGN CAPACITY OF THE PLANT: 9,5 Mℓ/day

RAW WATER QUALITY (Range)

Colour (apparent) (mg/ℓ as Pt)	30 - 110	pH	6,6 - 6,8
Colour (true) (mg/ℓ as Pt)		T Alkalinity (mg/ℓ as $CaCO_3$)	5 - 10
UV absorbance		Calcium (mg/ℓ as Ca)	2,2 - 3,2
Diss. organic carbon (mg/ℓ)		Magnesium (mg/ℓ as Mg)	
Turbidity (NTU)	2 - 10	T Hardness (mg/ℓ as $CaCO_3$)	
Conductivity (mS/m)	7 - 14	Sulphate (mg/ℓ as SO_4)	
Chloride (mg/ℓ as Cl)		Iron (mg/ℓ as Fe)	0,57 - 0,97
Sodium (mg/ℓ as Na)		Manganese (mg/ℓ as Mn)	< 0,02
Potassium (mg/ℓ as K)		Aluminium (mg/ℓ as Al)	0,1 - 1,2

TREATMENT PROCESSES

pH adjustment	- Lime - Aim at coagulation pH of 5,2 - Dose lime before alum
Coagulation	- Alum - Typical dosage: 15 mg/ℓ
Flocculation	- Flocculation channel - Occasionally dose nonionic polyelectrolyte
Settling	- 4 x horizontal flow settling tanks - Retention time: 4 hours - Desludge once per day
Additional chemicals	- None
Filtration	- 7 x rapid sand filters - Single medium; filter runs 40-60 hours - Recycle backwash water
Disinfection	- Chlorination with gaseous chlorine - Typical dosage: 2,9 mg/ℓ - Free chlorine residual of 0,8 mg/ℓ at the works
Stabilization	- Lime to obtain alkalinity of 30 mg/ℓ as $CaCO_3$ - CO_2 to bring pH down to 9,0 to 9,2

STEENBRAS
Cape Town Municipality

DESIGN CAPACITY OF THE PLANT: 114 Mℓ/day

RAW WATER QUALITY (Range)

Colour (apparent) (mg/ℓ as Pt)		pH	5,4 - 6,4
Colour (true) (mg/ℓ as Pt)	20 - 140	T Alkalinity (mg/ℓ as $CaCO_3$)	0,5 - 3,0
UV abs. @ 300 nm. (4 cm)	0,37 - 1,04	Calcium (mg/ℓ as Ca)	0,8 - 1,9
Diss. organic carbon (mg/ℓ)		Magnesium (mg/ℓ as Mg)	0,9 - 1,8
Turbidity (NTU)	3,3 - 10,9	T Hardness (mg/ℓ as $CaCO_3$)	5,8 - 12,3
Conductivity (mS/m)	5,3 - 9,1	Sulphate (mg/ℓ as SO_4)	1,7 - 6,1
Chloride (mg/ℓ as Cl)	13 - 20,5	Iron (mg/ℓ as Fe)	0,56 - 1,29
Sodium (mg/ℓ as Na)	7,9 - 12,2	Manganese (mg/ℓ as Mn)	0,01 - 0,03
Potassium (mg/ℓ as K)	0,3 - 1,0	Aluminium (mg/ℓ as Al)	0,21 - 0,41

TREATMENT PROCESSES

pH adjustment	- Lime - Typical dosage: 9,5 mg/ℓ - Aim at pH 6,3 for coagulation
Coagulation	- Sodium aluminate: typical dosage 5 mg/ℓ - Alum: typical dosage 27 mg/ℓ - Mixing in weir and baffled channel
Flocculation	- Conditioning tanks
Settling	- 6 x horizontal flow settling tanks - Retention time: 2,7 hours - 60 hoppers per tank
Additional chemicals	- 1,2 mg/ℓ chlorine before the filters
Filtration	- 20 x rapid sand filters - Single medium; filtration rate 4,9 m/h - Backwash water recycled
Disinfection	- Chlorination with gaseous chlorine - Maintain free chlorine residual of 0,5 - 0,6 mg/ℓ
Stabilization	- Lime to an alkalinity of 30 mg/ℓ - CO_2 to a pH of 9,2 - Coke for pH correction (now use gas)

FAURE
Cape Town Municipality

DESIGN CAPACITY OF THE PLANT:	500	Mℓ/day

RAW WATER QUALITY (Range)

Colour (apparent) (mg/ℓ as Pt)		pH	6,5 - 7,6
Colour (true) (mg/ℓ as Pt)	10 - 40	T Alkalinity (mg/ℓ as $CaCO_3$)	0,6 - 8,2
UV abs. @ 300 nm. (4 cm)	0,26-0,48	Calcium (mg/ℓ as Ca)	0,5 - 1,9
Diss. organic carbon (mg/ℓ)		Magnesium (mg/ℓ as Mg)	0,15 - 1,77
Turbidity (NTU)	1,1 - 7,3	T Hardness (mg/ℓ as $CaCO_3$)	6,0 - 18,8
Conductivity (mS/m)	3,3 - 7,7	Sulphate (mg/ℓ as SO_4)	1,5 - 4,7
Chloride (mg/ℓ as Cl)	6,3 - 13,7	Iron (mg/ℓ as Fe)	0,6 - 5,3
Sodium (mg/ℓ as Na)	3,5 - 8,3	Manganese (mg/ℓ as Mn)	0,002-0,159
Potassium (mg/ℓ as K)	0,4 - 1,1	Aluminium (mg/ℓ as Al)	0,04 - 0,44

TREATMENT PROCESSES

pH adjustment	- Lime - Typical dosage: 16 mg/ℓ
Coagulation	- Ferric sulphate - Typical dosage: 7 mg/ℓ as Fe - Mixing by weir and baffled channel
Flocculation	- Unstirred rectangular tanks - 3 banks, of 4 each, in series
Settling	- 8 x horizontal flow settling tanks - Retention time: 2,2 hours
Additional chemicals	- Activated carbon occasionally when taste and odour problems are experienced - Chlorine and lime (to alk. 30) before filters
Filtration	- 24 x declining flow rapid sand filters - Single medium; filtration rate 6-12 m/h - Filter runs: 24 hours
Disinfection	- Chlorination with gaseous chlorine - Dosage: 0,6 - 0,8 mg/ℓ
Stabilization	- Lime at 26 mg/ℓ before the filters to an alkalinity of 30 mg/ℓ as $CaCO_3$ - CO_2 to bring back pH to 9,0 - 9,2

BLACKHEATH
Cape Town Municipality

DESIGN CAPACITY OF THE PLANT: 360 Mℓ/day

RAW WATER QUALITY (Range)

Colour (apparent) (mg/ℓ as Pt)		pH	6,3 - 8,12
Colour (true) (mg/ℓ as Pt)	< 5 - 40	T Alkalinity (mg/ℓ as $CaCO_3$)	2,0 - 10,5
UV abs. @ 300 nm. (4 cm)	0,09-0,61	Calcium (mg/ℓ as Ca)	1,15 - 4,57
Diss. organic carbon (mg/ℓ)		Magnesium (mg/ℓ as Mg)	0,51 - 2,94
Turbidity (NTU)	0,86 - 20	T Hardness (mg/ℓ as $CaCO_3$)	4,9 - 20,7
Conductivity (mS/m)	3,1 - 11,1	Sulphate (mg/ℓ as SO_4)	0,46 - 4,9
Chloride (mg/ℓ as Cl)	7 - 21,5	Iron (mg/ℓ as Fe)	0,10 - 1,60
Sodium (mg/ℓ as Na)	4,1 - 13,3	Manganese (mg/ℓ as Mn)	0,001-0,36
Potassium (mg/ℓ as K)	0,4 - 1,5	Aluminium (mg/ℓ as Al)	0,24 - 1,20

TREATMENT PROCESSES

pH adjustment	- Lime - Typical dosage: 6 - 12 mg/ℓ
Coagulation	- Alum - Typical dosage: 20 - 40 mg/ℓ - Mixing at weir; $G > 30\ _{s}^{-1}$ and $_{t}$ = 60 sec.
Flocculation	- Unstirred chambers, two banks of 4 each in series - Flocculation time: 8 minutes
Settling	- 6 x horizontal flow settling tanks - Retention time: 2,25 hours - Settling tanks covered with asbestos sheets
Additional chemicals	- Occasionally powder activated carbon
Filtration	- 40 x rapid sand filters - Single medium; filtration rate 6 m/h - Backwashed routinely every 24 hours
Disinfection	- 1,5 mg/ℓ chlorine before the filters - 0,5 mg/ℓ chlorine after stabilisation - Aim at free chlorine residual of 0,7 mg/ℓ
Stabilization	- Lime to alkalinity of 30 mg/ℓ - CO_2 to a pH of 9,2

CONSTANTIA NEK
Cape Town Municipality

DESIGN CAPACITY OF THE PLANT: **3,0** **Mℓ/day**

RAW WATER QUALITY (Range)			
Colour (apparent) (mg/ℓ as Pt)		pH	4,5 - 5,4
Colour (true) (mg/ℓ as Pt)	120 - 240	T Alkalinity (mg/ℓ as $CaCO_3$)	0 - 1,0
UV abs. @ 300 nm. (4 cm)	1,5 - 2,2	Calcium (mg/ℓ as Ca)	1,0 - 2,4
Diss. organic carbon (mg/ℓ)		Magnesium (mg/ℓ as Mg)	1,0 - 2,1
Turbidity (NTU)	0,7 - 2,7	T Hardness (mg/ℓ as $CaCO_3$)	7 - 13,3
Conductivity (mS/m)	6,3 - 11,0	Sulphate (mg/ℓ as SO_4)	1,6 - 6,3
Chloride (mg/ℓ as Cl)	14,0-27,4	Iron (mg/ℓ as Fe)	0,13 - 0,23
Sodium (mg/ℓ as Na)	8,9 - 15,7	Manganese (mg/ℓ as Mn)	0,004-0,030
Potassium (mg/ℓ as K)	0,3 - 0,8	Aluminium (mg/ℓ as Al)	0,16 - 0,60

TREATMENT PROCESSES	
pH adjustment	- Lime - Typical dosage: 18 mg/ℓ - Aim at coagulation pH of 5,7
Coagulation	- Sodium aluminate: typical 11 mg/ℓ - Alum: typical 56 mgℓ - Hydraulic jump and baffled channel
Flocculation	- Unstirred chamber - 2 mg/ℓ activated silica to improve performance of sludge blanket settling tank
Settling	- 1 x horizontal flow with tube settlers (t = 1,0 hour) - 1 x sludge blanket clarifier (t = 3,3 hours)
Additional chemicals	- 1,3 mg/ℓ chlorine before filters
Filtration	- 4 x rapid sand filters - Single medium; filtration rate 4,2 m/h - Backwash routinely every 24 hours
Disinfection	- Chlorination with gaseous chlorine - Dosage: typical 1,2 mg/ℓ
Stabilization	- 30 mg/ℓ lime to give alkalinity of 30 mg/ℓ - Bring pH back to 9,2 with CO_2

KLOOFNEK
Cape Town Municipality

DESIGN CAPACITY OF THE PLANT: 16 Mℓ/day

RAW WATER QUALITY (Range)			
Colour (apparent) (mg/ℓ as Pt)		pH	4,3 - 5,3
Colour (true) (mg/ℓ as Pt)	120 - 240	T Alkalinity (mg/ℓ as $CaCO_3$)	0 - 1,3
UV abs. @ 300 nm. (4 cm)	1,7 - 2,6	Calcium (mg/ℓ as Ca)	1,0 - 2,3
Diss. organic carbon (mg/ℓ)		Magnesium (mg/ℓ as Mg)	0,8 - 2,0
Turbidity (NTU)	1,2 - 5,8	T Hardness (mg/ℓ as $CaCO_3$)	5,8 - 13,7
Conductivity (mS/m)	5,3 - 10,2	Sulphate (mg/ℓ as SO_4)	1,1 - 5,8
Chloride (mg/ℓ as Cl)	12,2-24,5	Iron (mg/ℓ as Fe)	0,13 - 0,29
Sodium (mg/ℓ as Na)	6,9 - 13,0	Manganese (mg/ℓ as Mn)	0,001-0,027
Potassium (mg/ℓ as K)	0,3 - 0,9	Aluminium (mg/ℓ as Al)	0,11 - 0,34

TREATMENT PROCESSES	
pH adjustment	- Lime - Typical dosage: 15,5 mg/ℓ - Aim at coagulation pH of 5,7
Coagulation	- Sodium aluminate: typical 9 mg/ℓ - Alum: typical 55 mg/ℓ - Hydraulic jump and mixing race
Flocculation	- Unstirred chamber
Settling	- 2 x horizontal flow settling tanks - Retention time: 4,7 hours
Additional chemicals	- 1,4 mg/ℓ chlorine before the filters
Filtration	- 6 x rapid sand filters - Single medium; filtration rate 3,8 m/h - Backwash routinely every 24 hours
Disinfection	- Chlorination with gaseous chlorine - Maintain free chlorine residual of 0,8-1,0 mg/ℓ - Contact time: 1 hour
Stabilization	- Lime (39 mg/ℓ) to alkalinity 30 mg/ℓ - 20 mg/ℓ CO_2 to bring pH back to 9,0 - 9,2

GROOTBRAK
Great Brak River Municipality

DESIGN CAPACITY OF THE PLANT: 4,0 Mℓ/day

RAW WATER QUALITY (Range)			
Colour (apparent) (mg/ℓ as Pt)	250 - 680	pH	3,9 - 5,9
Colour (true) (mg/ℓ as Pt)	185 - 460	T Alkalinity (mg/ℓ as $CaCO_3$)	0 - 2,0
UV absorbance @ nm.		Calcium (mg/ℓ as Ca)	
Diss. organic carbon (mg/ℓ)	9,6	Magnesium (mg/ℓ as Mg)	
Turbidity (NTU)	4,1 - 20	T Hardness (mg/ℓ as $CaCO_3$)	11 - 69
Conductivity (mS/m)	5 - 11	Sulphate (mg/ℓ as SO_4)	
Chloride (mg/ℓ as Cl)		Iron (mg/ℓ as Fe)	
Sodium (mg/ℓ as Na)		Manganese (mg/ℓ as Mn)	
Potassium (mg/ℓ as K)		Aluminium (mg/ℓ as Al)	

TREATMENT PROCESSES	
pH adjustment	- Lime - Dosed after alum in the mixing range
Coagulation	- Alum - Typical dosage: 50 mg/ℓ - Rapid mixing in mixing race
Flocculation	- Vertical baffle flocculation channel
Settling	- 2 x horizontal flow settling tanks
Additional chemicals	
Filtration	- 2 x rapid sand filters - Multimedia - Backwash 2 times per week
Disinfection	- Liquid calcium hypochlorite - Maintain free chlorine residual of 0,5 mg/ℓ - Chlorine dosed before lime for stabilisation
Stabilization	- Lime - Maintain final pH of 9,0 - 9,2

GEORGE OLD
George Municipality

DESIGN CAPACITY OF THE PLANT:	20	Mℓ/day

RAW WATER QUALITY (Range or typical)

Colour (apparent) (mg/ℓ as Pt)	200 - 600	pH	4,0
Colour (true) (mg/ℓ as Pt)		T Alkalinity (mg/ℓ as $CaCO_3$)	0
UV absorbance		Calcium (mg/ℓ as Ca)	
Diss. organic carbon (mg/ℓ)		Magnesium (mg/ℓ as Mg)	
Turbidity (NTU)		T Hardness (mg/ℓ as $CaCO_3$)	
Conductivity (mS/m)		Sulphate (mg/ℓ as SO_4)	
Chloride (mg/ℓ as Cl)		Iron (mg/ℓ as Fe)	
Sodium (mg/ℓ as Na)		Manganese (mg/ℓ as Mn)	
Potassium (mg/ℓ as K)		Aluminium (mg/ℓ as Al)	

TREATMENT PROCESSES

pH adjustment	- Lime - Typical dosage: 40 mg/ℓ - Dosed after alum
Coagulation	- Alum - Typical dosage: 140 mg/ℓ - Rapid mixing with hydraulic jump
Flocculation	- Flocculation channel - Dose LT 20 at end of flocculation channel
Settling	- Horizontal flow settling tanks
Additional chemicals	
Filtration	- Rapid sand filters
Disinfection	- Chlorination with gaseous chlorine - Chlorine dosed before lime for stabilisation
Stabilization	- Lime - Typical dosage: 14 mg/ℓ

GEORGE NEW
George Municipality

DESIGN CAPACITY OF THE PLANT:	60	Mℓ/day

RAW WATER QUALITY (Range)

Colour (apparent) (mg/ℓ as Pt)	500 - 1100	pH	3,8 - 4,5
Colour (true) (mg/ℓ as Pt)		T Alkalinity (mg/ℓ as $CaCO_3$)	0
UV absorbance		Calcium (mg/ℓ as Ca)	
Diss. organic carbon (mg/ℓ)		Magnesium (mg/ℓ as Mg)	
Turbidity (NTU)	0,1 - 10	T Hardness (mg/ℓ as $CaCO_3$)	
Conductivity (mS/m)		Sulphate (mg/ℓ as SO_4)	30 - 60
Chloride (mg/ℓ as Cl)		Iron (mg/ℓ as Fe)	1,0 - 1,5
Sodium (mg/ℓ as Na)		Manganese (mg/ℓ as Mn)	
Potassium (mg/ℓ as K)		Aluminium (mg/ℓ as Al)	0,5 - 1,0

TREATMENT PROCESSES

pH adjustment	- Lime - Dosed after ferric chloride in the mixing race
Coagulation	- Ferric chloride - Typical dosage: 140 mg/ℓ - Rapid mixing in mixing basin/distributor
Flocculation	- Horizontal baffle flocculation channel - Flocculation time: 15 minutes - Dose 0,075 mg/ℓ LT 20 for floc strength
Settling	- 2 x horizontal flow settling tanks - Retention time: 1,77 hours - Settling velocity: 1,76 m/h
Additional chemicals	- Chlorine before filtration for Fe-oxidation - Lime to raise pH to 7,0 for Fe/Al precipitation
Filtration	- Rapid sand filters - Filtration rate: 6 m/h - Backwash routinely every 48 hours
Disinfection	- Chlorination with gaseous chlorine - Chlorine residual at furthest point: 0,02 mg/ℓ - Chlorine dosed before lime for stabilisation
Stabilization	- Lime (experimenting with limestone)

WILDERNESS
Southern Cape District Council

DESIGN CAPACITY OF THE PLANT: 2,0 Mℓ/day

RAW WATER QUALITY (Typical)

Colour (apparent) (mg/ℓ as Pt)	150	pH	5,1
Colour (true) (mg/ℓ as Pt)	120	T Alkalinity (mg/ℓ as $CaCO_3$)	2,0
UV absorbance		Calcium (mg/ℓ as Ca)	
Diss. organic carbon (mg/ℓ)	11,4	Magnesium (mg/ℓ as Mg)	
Turbidity (NTU)	0,7	T Hardness (mg/ℓ as $CaCO_3$)	21
Conductivity (mS/m)		Sulphate (mg/ℓ as SO_4)	
Chloride (mg/ℓ as Cl)		Iron (mg/ℓ as Fe)	0,61
Sodium (mg/ℓ as Na)		Manganese (mg/ℓ as Mn)	
Potassium (mg/ℓ as K)		Aluminium (mg/ℓ as Al)	

TREATMENT PROCESSES

pH adjustment	- Soda-ash - Typical dosage: 26 mg/ℓ - Dosed at same point as alum
Coagulation	- Alum - Typical dosage: 50 mg/ℓ
Flocculation	- First in flocculation channel; then in pipes crossing settling tank - Flocculation time: 6 minutes
Settling	- 4 x horizontal flow primary settling tanks - 4 x horizontal flow secondary settling tanks - Retention time in total system: 4 hours
Additional chemicals	
Filtration	- No filtration. Previously had slow sand filters but converted the slow sand filters to secondary setttling tanks
Disinfection	- Liquid chlorine dosing (HTH make-up) - Chlorine dosed after lime for stabilisation
Stabilization	- Lime - Aim at final pH of 9,0

SEDGEFIELD
Sedgefield Municipality

DESIGN CAPACITY OF THE PLANT: 4,0 Mℓ/day

RAW WATER QUALITY (Typical)			
Colour (apparent) (mg/ℓ as Pt)	350	pH	5,4
Colour (true) (mg/ℓ as Pt)	320	T Alkalinity (mg/ℓ as $CaCO_3$)	3,5
UV absorbance		Calcium (mg/ℓ as Ca)	
Diss. organic carbon (mg/ℓ)	18,6	Magnesium (mg/ℓ as Mg)	
Turbidity (NTU)	1,2	T Hardness (mg/ℓ as $CaCO_3$)	29
Conductivity (mS/m)		Sulphate (mg/ℓ as SO_4)	
Chloride (mg/ℓ as Cl)		Iron (mg/ℓ as Fe)	1,26
Sodium (mg/ℓ as Na)		Manganese (mg/ℓ as Mn)	
Potassium (mg/ℓ as K)		Aluminium (mg/ℓ as Al)	

TREATMENT PROCESSES	
pH adjustment	- Lime - Typical dosage: 40 mg/ℓ - Dosed before alum in the mixing race
Coagulation	- Alum (later changed to ferric chloride) - Typical dosage: Alum 90 - 150 mg/ℓ - Rapid mixing with hydraulic jump
Flocculation	- Vertical plates at entrance to settling tanks - Dose 0,15 - 0,2 mg/ℓ LT 25 to increase floc strength
Settling	- 2 x horizontal flow settling tanks
Additional chemicals	
Filtration	- 2 x new rapid sand filters
Disinfection	- Chlorination with gaseous chlorine - Chlorine dosed after lime for stabilisation
Stabilization	- Lime - Typical dosage: 30 - 35 mg/ℓ

KNYSNA
Knysna Municipality

DESIGN CAPACITY OF THE PLANT:	5,0	Mℓ/day

RAW WATER QUALITY (Typical)

Colour (apparent) (mg/ℓ as Pt)	60	pH	5,2
Colour (true) (mg/ℓ as Pt)		T Alkalinity (mg/ℓ as $CaCO_3$)	6
UV absorbance		Calcium (mg/ℓ as Ca)	
Diss. organic carbon (mg/ℓ)		Magnesium (mg/ℓ as Mg)	
Turbidity (NTU)	1,2	T Hardness (mg/ℓ as $CaCO_3$)	24
Conductivity (mS/m)	22	Sulphate (mg/ℓ as SO_4)	
Chloride (mg/ℓ as Cl)		Iron (mg/ℓ as Fe)	
Sodium (mg/ℓ as Na)		Manganese (mg/ℓ as Mn)	
Potassium (mg/ℓ as K)		Aluminium (mg/ℓ as Al)	

TREATMENT PROCESSES

pH adjustment	- Lime - Typical dosage: 23 mg/ℓ - Lime dosed before alum
Coagulation	- Alum - Typical dosage: 50 mg/ℓ - Mixing in mixing race
Flocculation	- Flocculation channel
Settling	- 2 x horizontal flow settling tanks - Retention time: 5 hours - Desludged daily
Additional chemicals	
Filtration	- 6 x rapid sand filters - Backwashing system recently upgraded
Disinfection	- Chlorination with gaseous chlorine - Dosage: 1,1 mg/ℓ - Maintain free chlorine residual of 0,8 mg/ℓ at plant outlet
Stabilization	- Disinfection before stabilisation - Lime dosed at 12 mg/ℓ - Aim at final pH of 9,0

PLETTENBERG BAY
Plettenberg Bay Municipality

DESIGN CAPACITY OF THE PLANT:	12	Mℓ/day

RAW WATER QUALITY (Range or typical)

Colour (apparent) (mg/ℓ as Pt)	45 - 390	pH	5,2
Colour (true) (mg/ℓ as Pt)		T Alkalinity (mg/ℓ as $CaCO_3$)	18 - 29
UV absorbance		Calcium (mg/ℓ as Ca)	
Diss. organic carbon (mg/ℓ)		Magnesium (mg/ℓ as Mg)	
Turbidity (NTU)	0,8 - 25	T Hardness (mg/ℓ as $CaCO_3$)	
Conductivity (mS/m)	7,5 - 15,5	Sulphate (mg/ℓ as SO_4)	0 - 41
Chloride (mg/ℓ as Cl)		Iron (mg/ℓ as Fe)	0,01 - 0,03
Sodium (mg/ℓ as Na)		Manganese (mg/ℓ as Mn)	
Potassium (mg/ℓ as K)		Aluminium (mg/ℓ as Al)	0,08 - 4,0

TREATMENT PROCESSES

pH adjustment	- Lime - Typical dosage: 12 mg/ℓ - Low pH: dose lime first; high pH: dose alum first
Coagulation	- Alum - Typical dosage: 30 mg/ℓ - Hydraulic jump and mixing race
Flocculation	- Baffled channel - Flocculation time: 15 minutes
Settling	- 2 x circular settling tanks - Settling velocity: 0,8 m/h - Bottom of tanks flat
Additional chemicals	
Filtration	- 9 x rapid sand filters - Single medium - Recycle backwash water to inlet of works
Disinfection	- Chlorination with gaseous chlorine - Dosage: 1,2- 2,4 mg/ℓ - Free chlorine residual of 0,4 - 0,6 mg/ℓ
Stabilization	- Disinfection done before stabilisation - Aim at final pH of 8,5 - 9,0

DETAILS OF WATER SUPPLIERS AND CONTACT PERSONS

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ANNEXURE C

RESULTS OF BENCH-SCALE TESTS

COAGULATION BEAKER TESTS

All coagulation beaker tests reported on here were carried out according to the procedure given in Annexure E of this document.

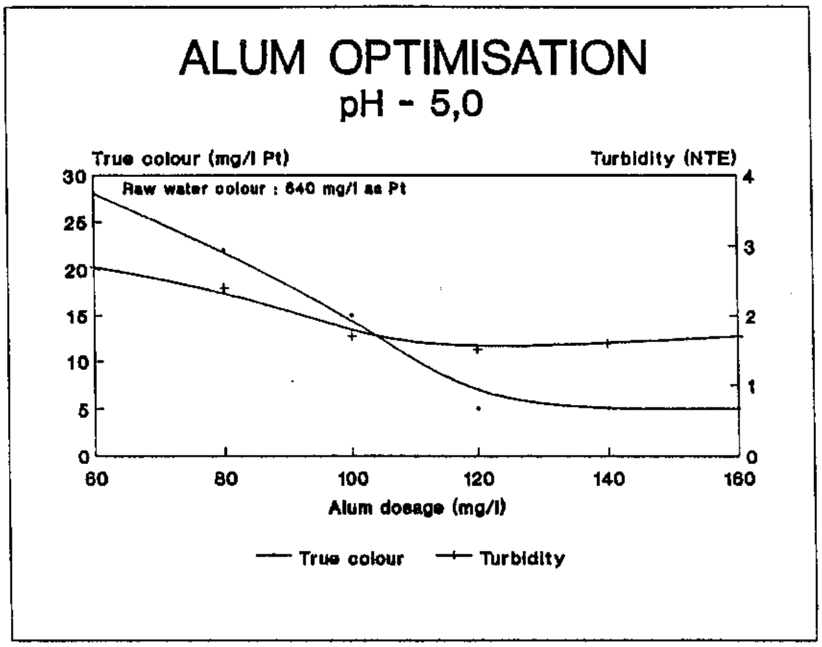
2 litre square plexiglass beakers were used together with a Phipps and Bird stirrer.

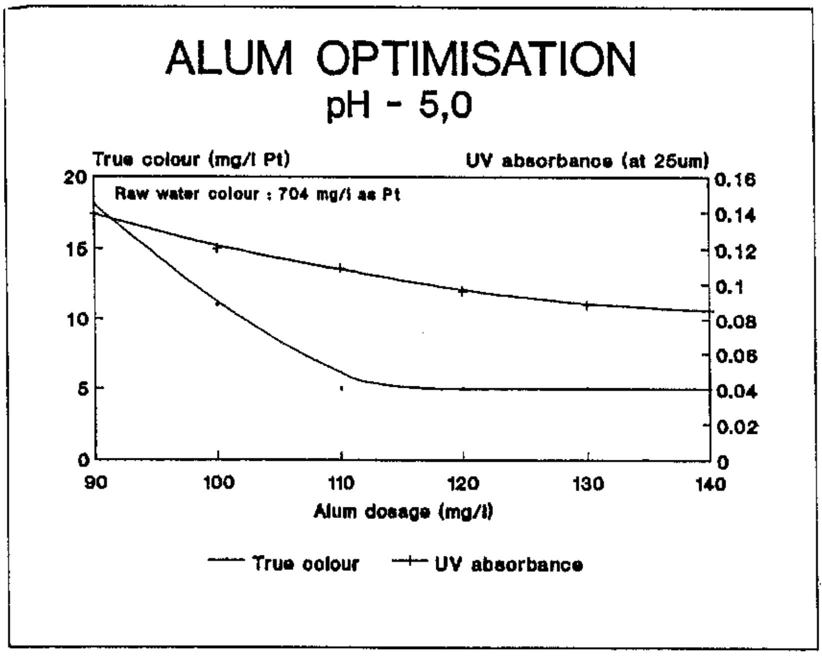
TESTS DONE AT
SANDHOOGTE WATER TREATMENT PLANT
MOSSEL BAY

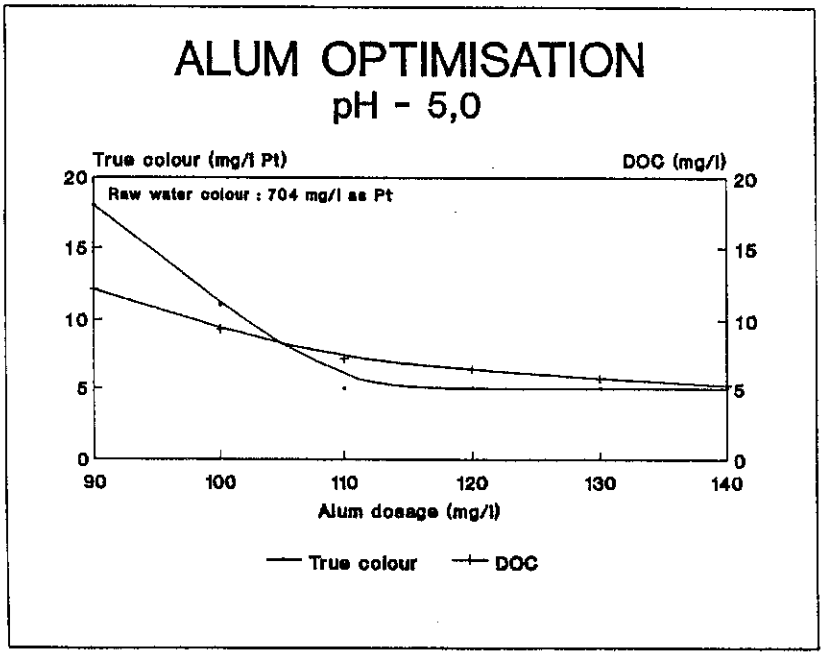
Quality of Sandhoogte Raw Water
(ex Ernest Robertson Dam)

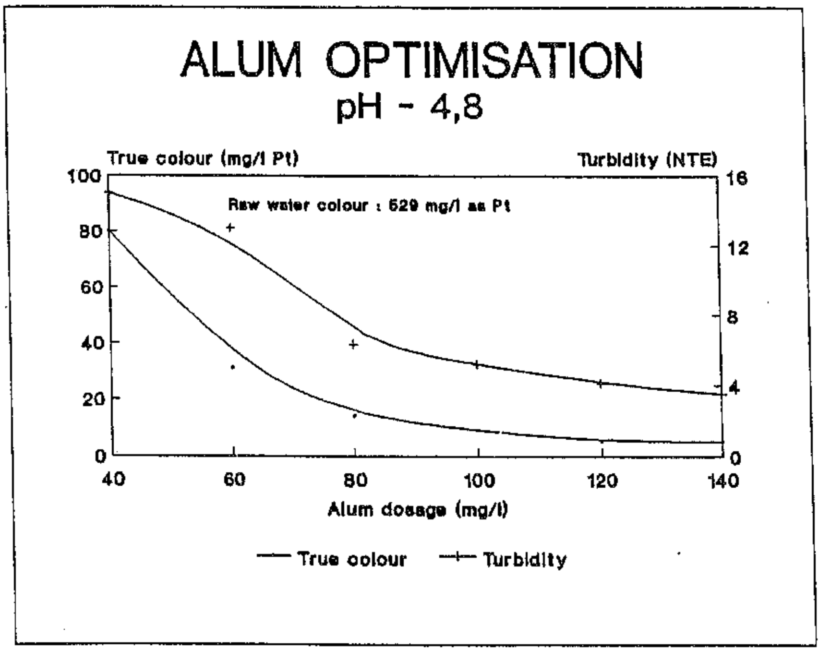
QUALITY PARAMETER	RANGE
Apparent colour (mg/ℓ as Pt)	366 - 960
True colour (mg/ℓ as Pt)	150 - 886
UV Absorbance	2,38 - 4,33 (*) (254nm 4 cm)
DOC (mg/ℓ)	8 - 25 (*)
Turbidity (NTU)	0,50 - 2,2
pH	3,2 - 5,3
Alkalinity (mg/l as $CaCO_3$)	0 - 0,8
Calcium (mg/l as $CaCO_3$)	4 - 63
Magnesium (mg/l as $CaCO_3$)	4 - 17
Conductivity (mS/m)	5 - 14
Chlorides (mg/ℓ as Cl)	5 - 103
Iron (mg/ℓ as Fe)	0,30 - 0,85
Manganese (mg/ℓ as Mn)	0 - 0,18
Temperature (°C)	11 - 21
Raw water classification	High colour Low turb. Medium iron

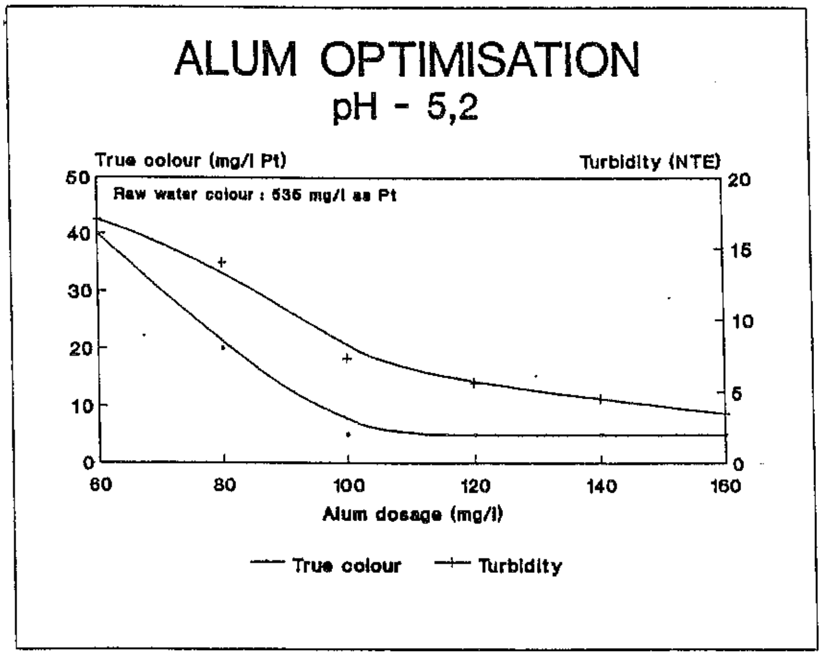
(*) Occasional measurements

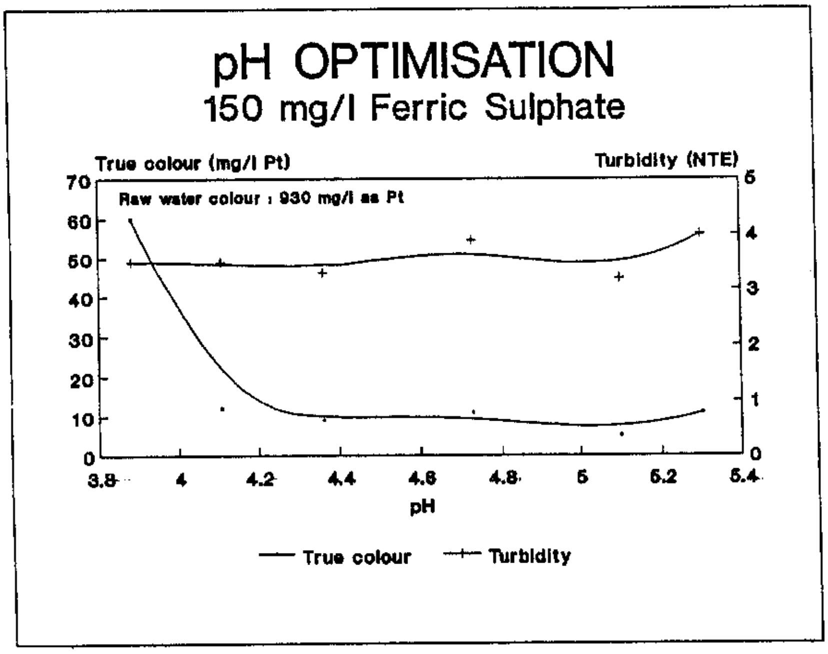

ALUM OPTIMISATION
pH - 5,0
True colour (mg/l Pt)
Turbidity (NTE)
Raw water colour : 640 mg/l as Pt
30
25
20
15
10
5
0
4
3
2
1
0
60
80
100
120
140
160
Alum dosage (mg/l)
True colour
Turbidity


ALUM OPTIMISATION
pH - 5,0
True colour (mg/l Pt)
UV absorbance (at 25um)
Raw water colour : 704 mg/l as Pt
20
15
10
5
0
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
90
100
110
120
130
140
Alum dosage (mg/l)
True colour
UV absorbance

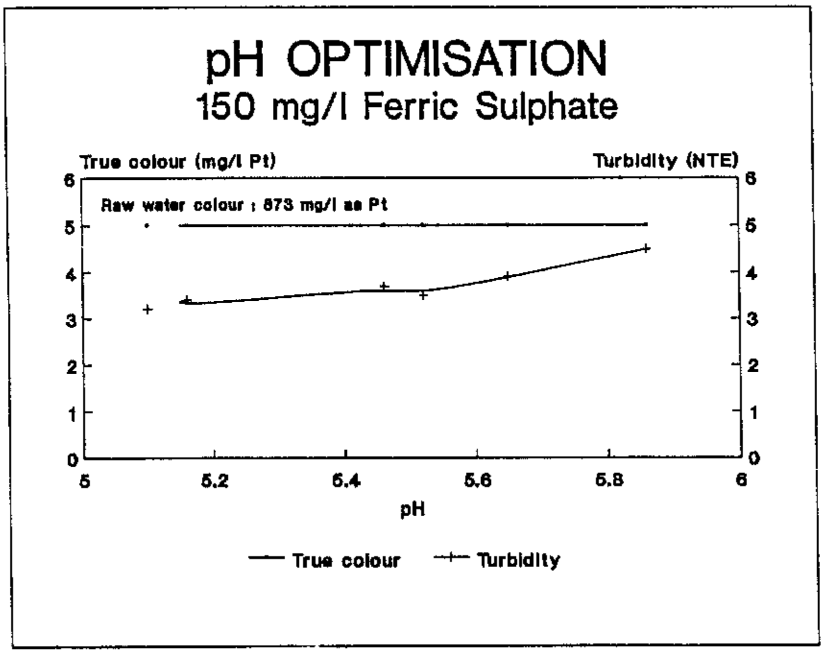

ALUM OPTIMISATION
pH - 5,0
True colour (mg/l Pt)
DOC (mg/l)
Raw water colour : 704 mg/l as Pt
20
15
10
5
0
20
15
10
5
0
90
100
110
120
130
140
Alum dosage (mg/l)
True colour
DOC


ALUM OPTIMISATION
pH - 4,8
True colour (mg/l Pt)
Turbidity (NTE)
Raw water colour : 529 mg/l as Pt
100
80
60
40
20
0
16
12
8
4
0
40
60
80
100
120
140
Alum dosage (mg/l)
True colour
Turbidity

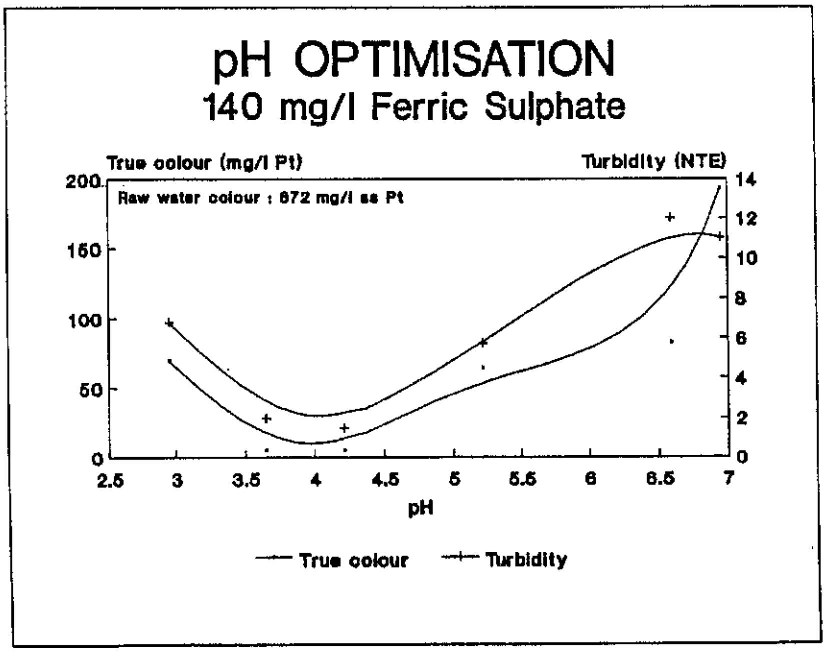

ALUM OPTIMISATION
pH - 5,2
True colour (mg/l Pt)
Turbidity (NTE)
Raw water colour : 535 mg/l as Pt
50
40
30
20
10
0
20
15
10
5
0
60
80
100
120
140
160
Alum dosage (mg/l)
True colour
Turbidity



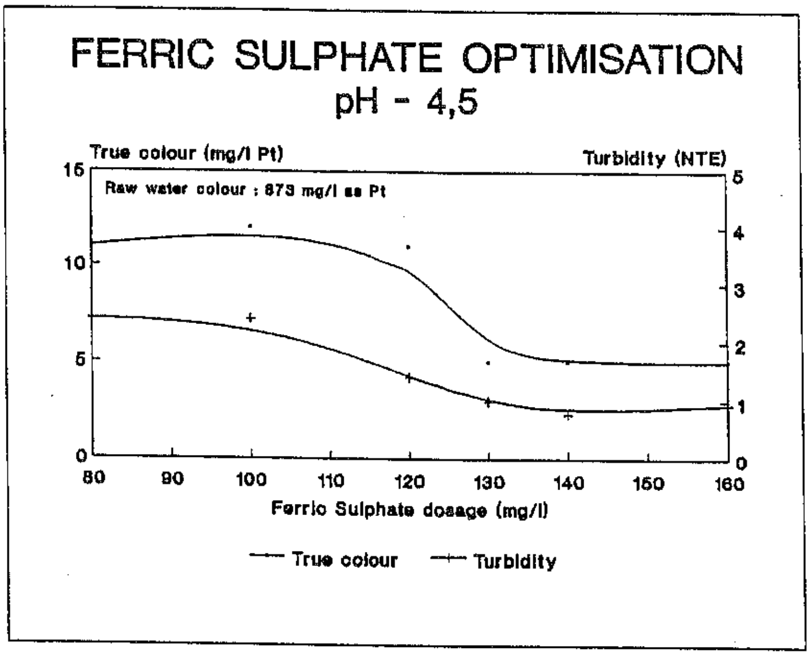
pH OPTIMISATION
150 mg/l Ferric Sulphate

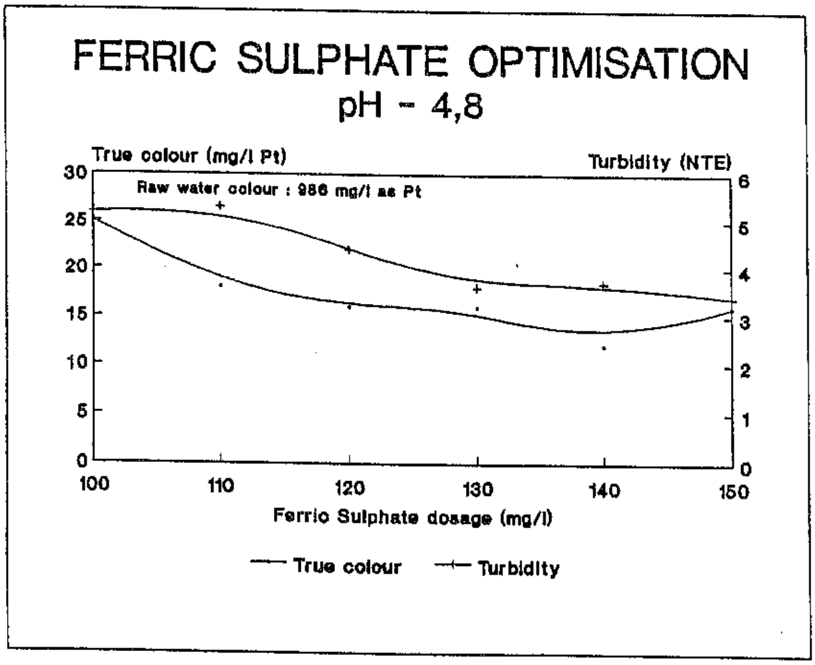


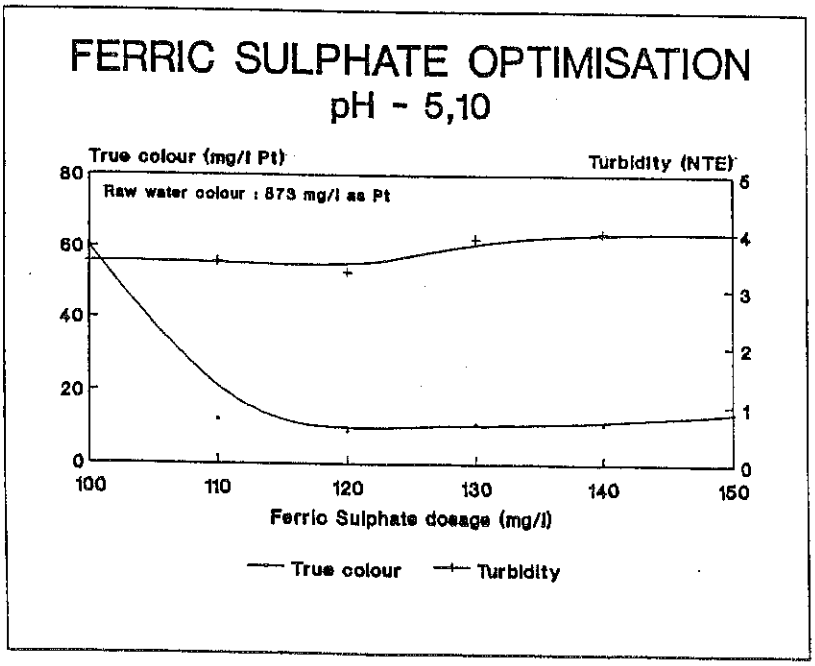
pH OPTIMISATION
150 mg/l Ferric Sulphate

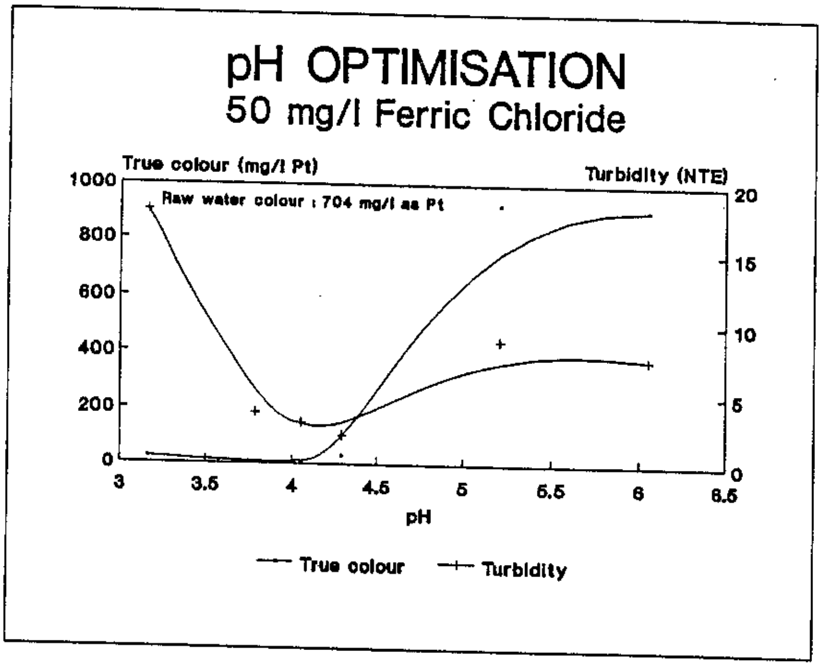


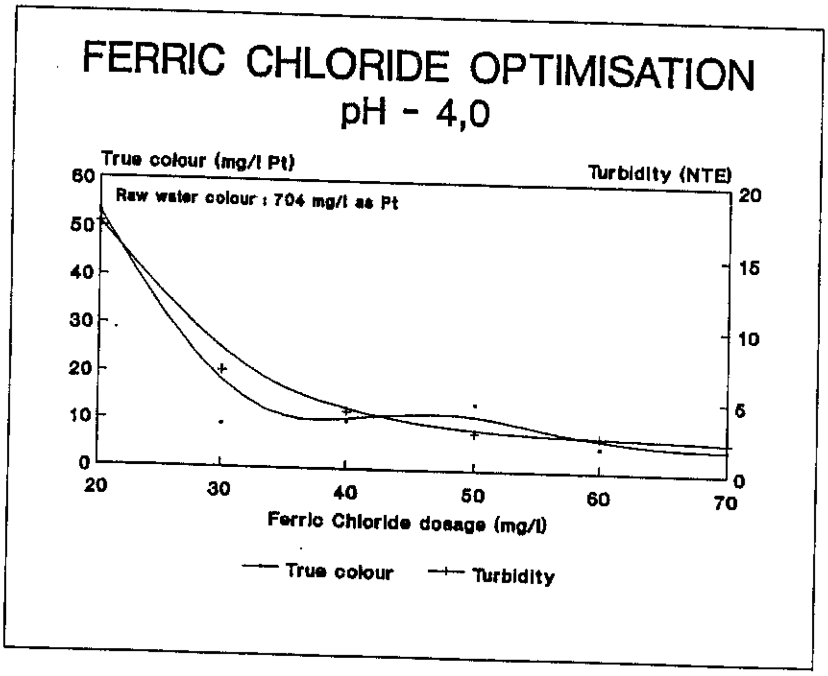
pH OPTIMISATION
140 mg/l Ferric Sulphate

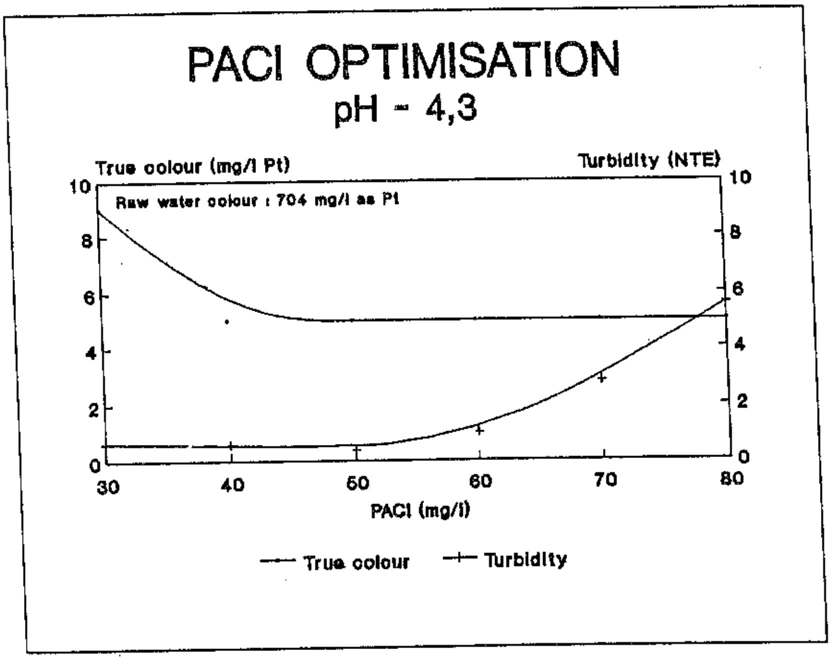

FERRIC SULPHATE OPTIMISATION
pH - 4,5
True colour (mg/l Pt)
Turbidity (NTE)
Raw water colour : 873 mg/l as Pt
0
5
10
15
0
1
2
3
4
5
80
90
100
110
120
130
140
150
160
Ferric Sulphate dosage (mg/l)
True colour
Turbidity

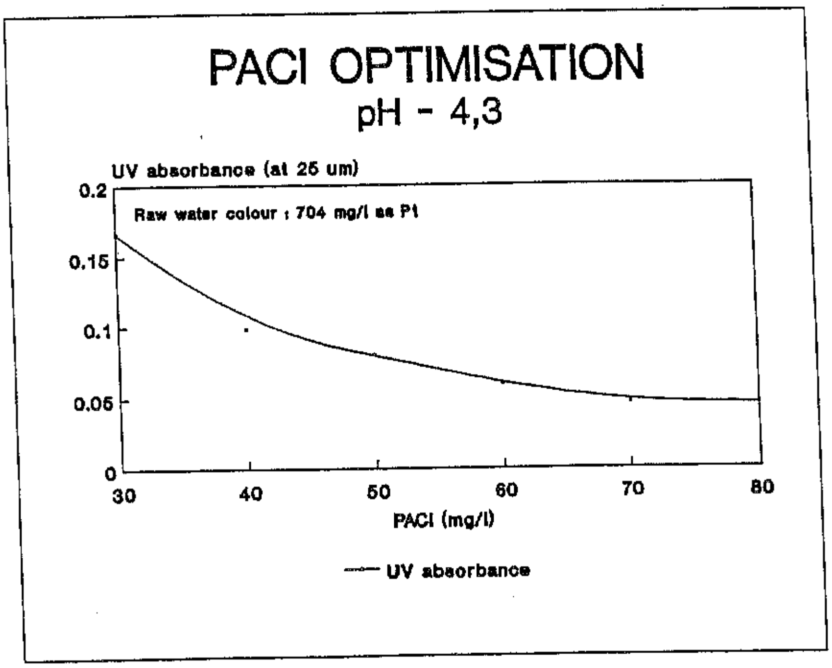

FERRIC SULPHATE OPTIMISATION
pH - 4,8
True colour (mg/l Pt)
Turbidity (NTE)
Raw water colour : 986 mg/l as Pt
0
5
10
15
20
25
30
0
1
2
3
4
5
6
100
110
120
130
140
150
Ferric Sulphate dosage (mg/l)
True colour
Turbidity


FERRIC SULPHATE OPTIMISATION
pH - 5,10
True colour (mg/l Pt)
Turbidity (NTE)
Raw water colour : 873 mg/l as Pt
0
20
40
60
80
0
1
2
3
4
5
100
110
120
130
140
150
Ferric Sulphate dosage (mg/l)
True colour
Turbidity


pH OPTIMISATION
50 mg/l Ferric Chloride
True colour (mg/l Pt)
Turbidity (NTE)
Raw water colour : 704 mg/l as Pt
1000
800
600
400
200
0
20
15
10
5
0
3
3.5
4
4.5
5
5.5
6
6.5
pH
True colour
Turbidity


FERRIC CHLORIDE OPTIMISATION
pH - 4,0
True colour (mg/l Pt)
Turbidity (NTE)
Raw water colour : 704 mg/l as Pt
60
50
40
30
20
10
0
20
15
10
5
0
20
30
40
50
60
70
Ferric Chloride dosage (mg/l)
True colour
Turbidity


PACl OPTIMISATION
pH - 4,3
True colour (mg/l Pt)
Turbidity (NTE)
Raw water colour : 704 mg/l as Pt
10
8
6
4
2
0
30
40
50
60
70
80
PACl (mg/l)
True colour
Turbidity

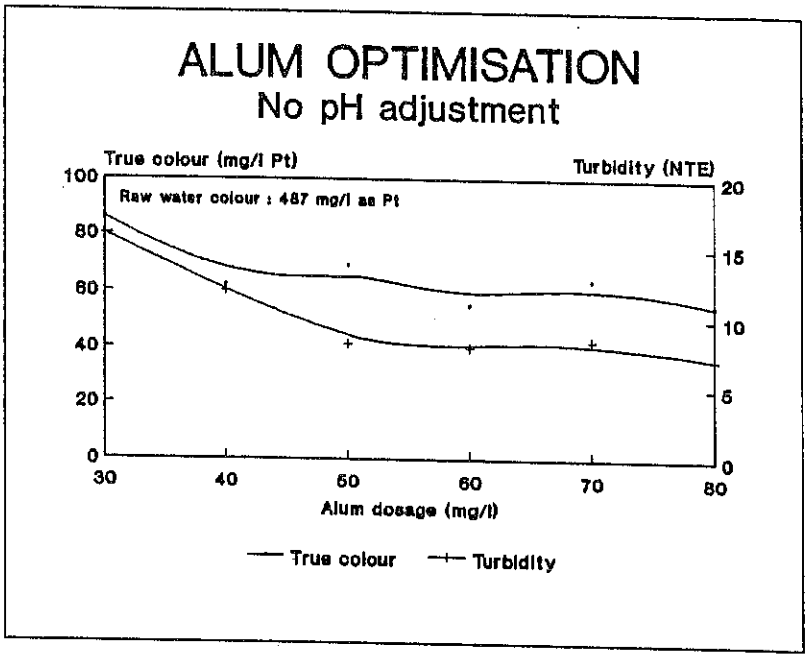

PACl OPTIMISATION
pH - 4,3
UV absorbance (at 25 um)
Raw water colour : 704 mg/l as Pt
0.2
0.15
0.1
0.05
0
30
40
50
60
70
80
PACl (mg/l)
UV absorbance

TESTS DONE AT
KLEINBRAK WATER TREATMENT PLANT
MOSSEL BAY

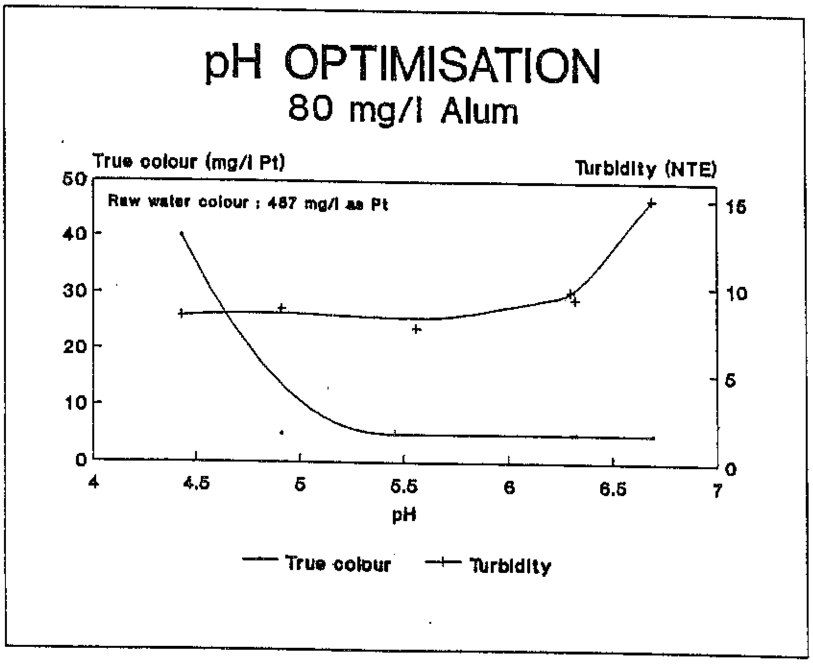
Quality of Kleinbrak Raw Water
(ex Klipheuwel Dam and/or Wolwedans Dam)

QUALITY PARAMETER	RANGE
Apparent colour (mg/ℓ as Pt)	322 - 770
True colour (mg/ℓ as Pt)	45 - 487
Turbidity (NTU)	6,9 - 45
pH	3,7 - 7,7
Alkalinity (mg/l as $CaCO_3$)	0 - 52
Calcium (mg/l as $CaCO_3$)	11 - 82
Magnesium (mg/l as $CaCO_3$)	7 - 68
Conductivity (mS/m)	7 - 55
Chlorides (mg/ℓ as Cl)	25 - 179
Iron (mg/ℓ as Fe)	0 - 9,2
Manganese (mg/ℓ as Mn)	0 - 0,76
Temperature (°C)	10 - 22
Raw water classification	High colour High turb. High iron

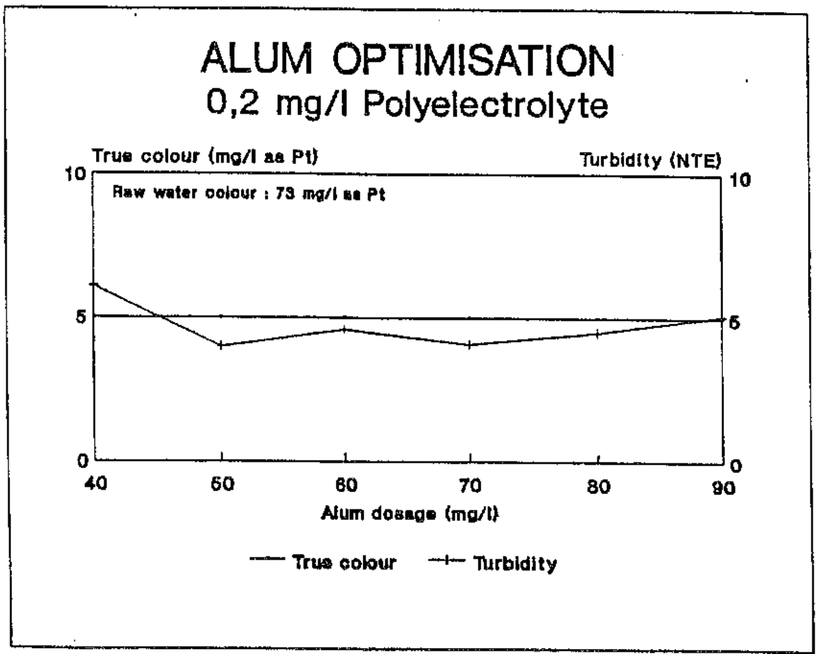
(*) Measured occasionaly



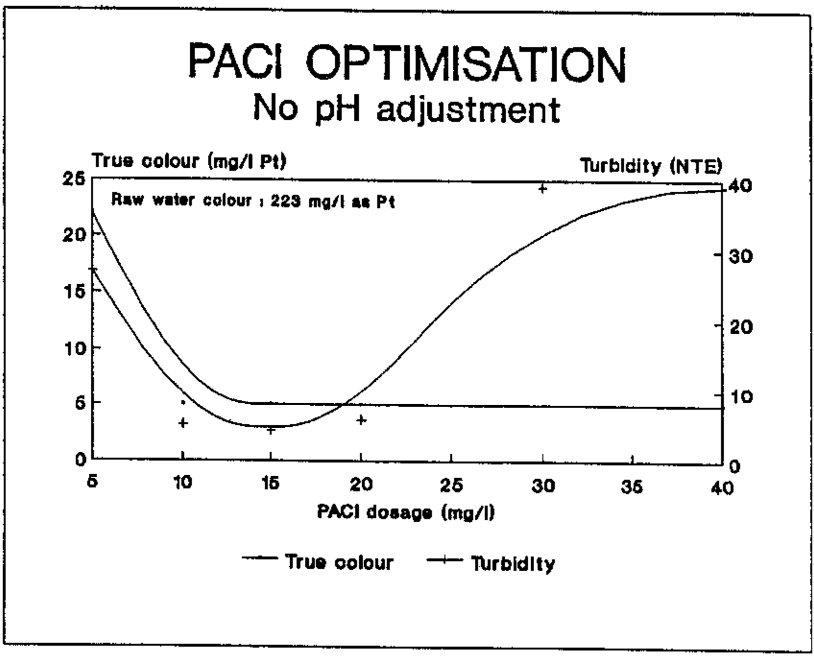
ALUM OPTIMISATION
No pH adjustment

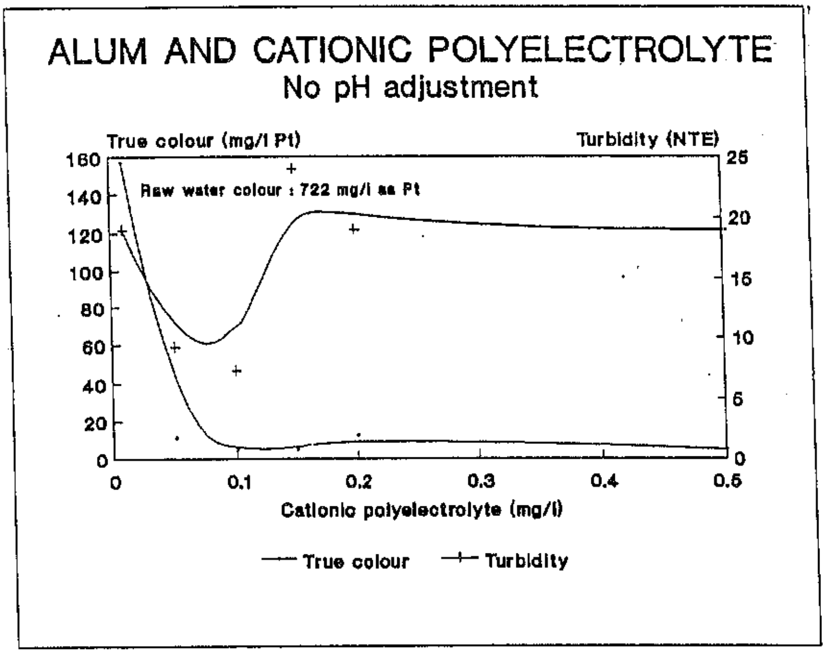


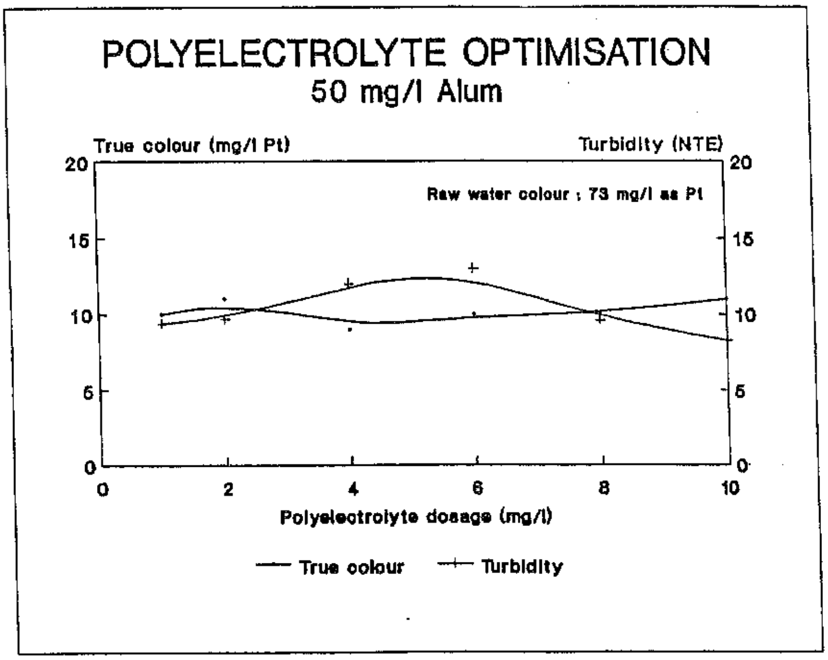
pH OPTIMISATION
80 mg/l Alum

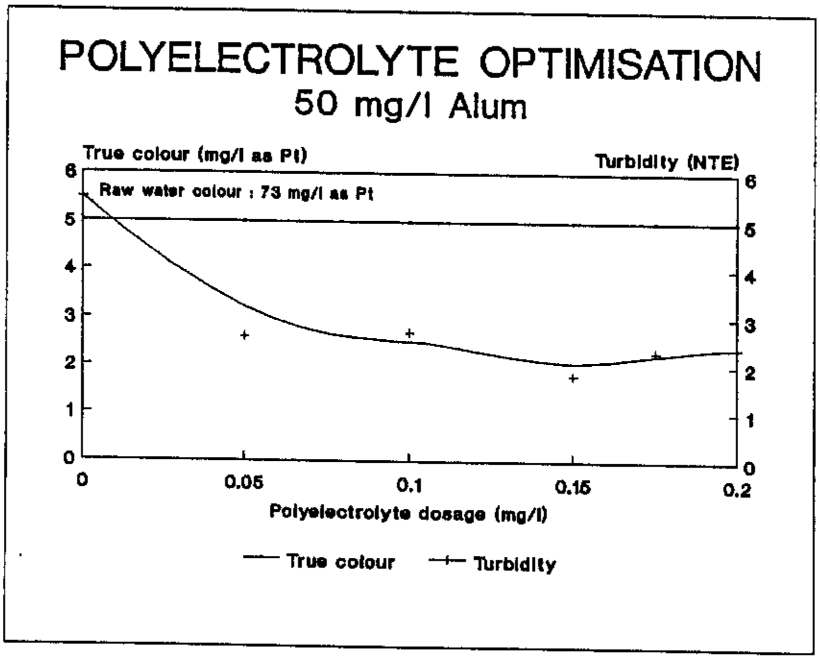


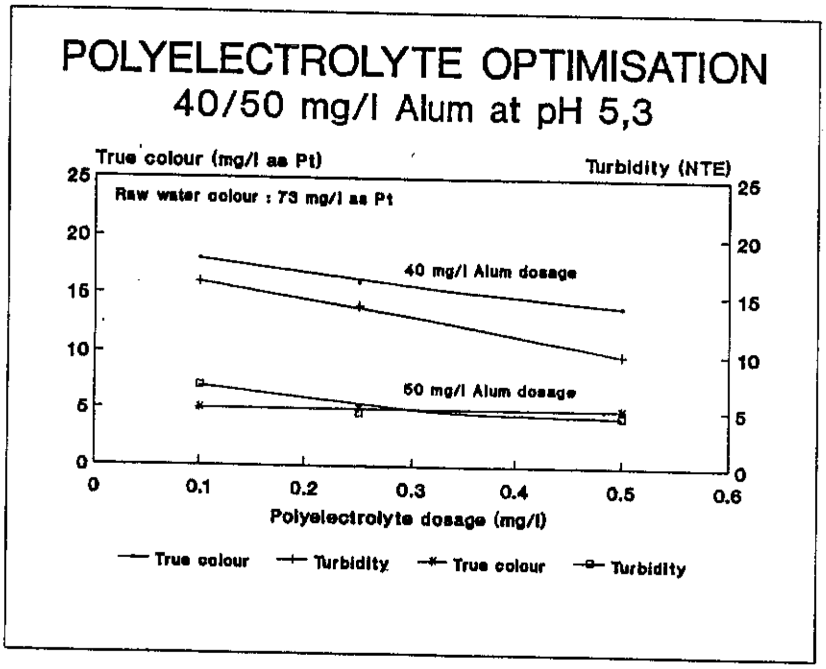
ALUM OPTIMISATION
0,2 mg/l Polyelectrolyte

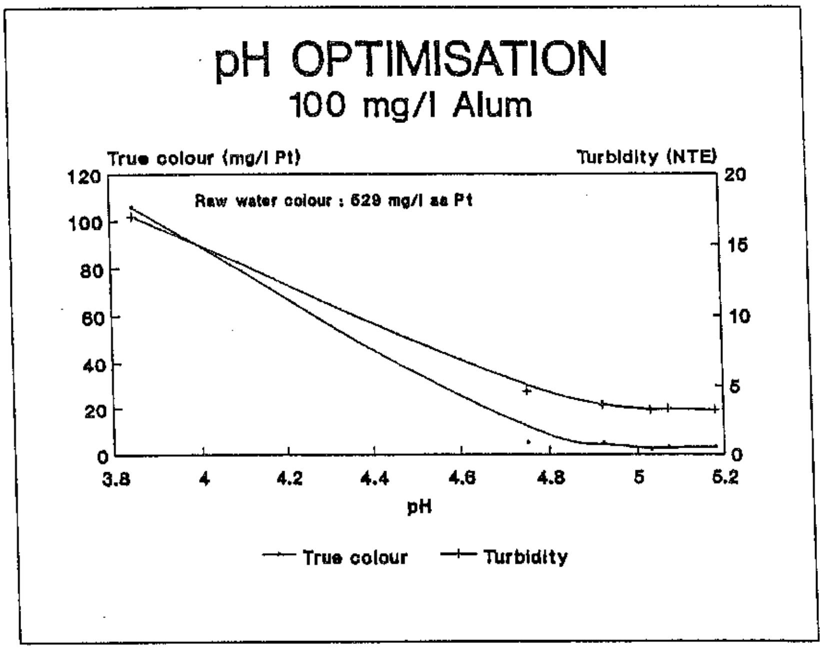

PACl OPTIMISATION
No pH adjustment
True colour (mg/l Pt)
Turbidity (NTE)
Raw water colour : 223 mg/l as Pt
25
20
15
10
5
0
40
30
20
10
0
5
10
15
20
25
30
35
40
PACl dosage (mg/l)
True colour
Turbidity

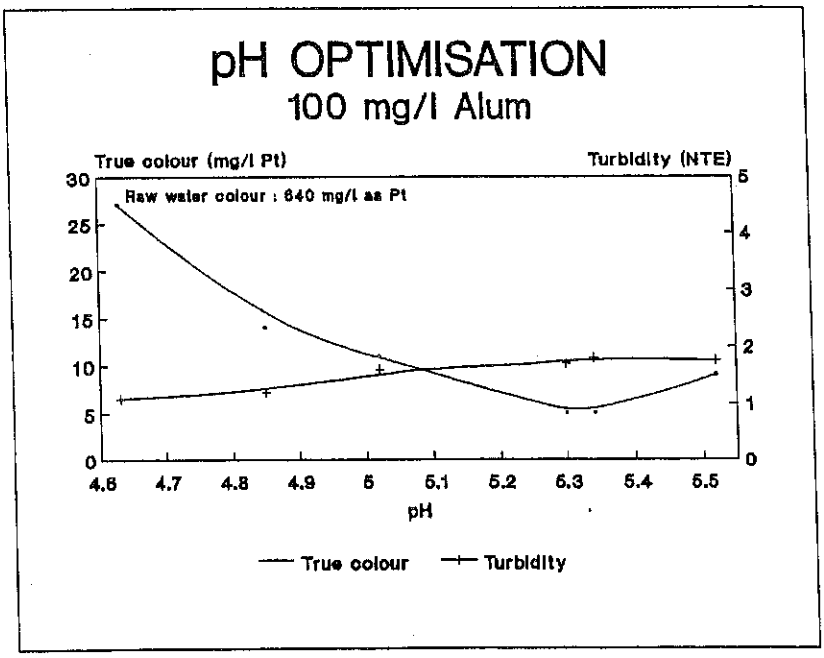

ALUM AND CATIONIC POLYELECTROLYTE
No pH adjustment
True colour (mg/l Pt)
Turbidity (NTE)
Raw water colour : 722 mg/l as Pt
160
140
120
100
80
60
40
20
0
25
20
15
10
5
0
0
0.1
0.2
0.3
0.4
0.5
Cationic polyelectrolyte (mg/l)
True colour
Turbidity

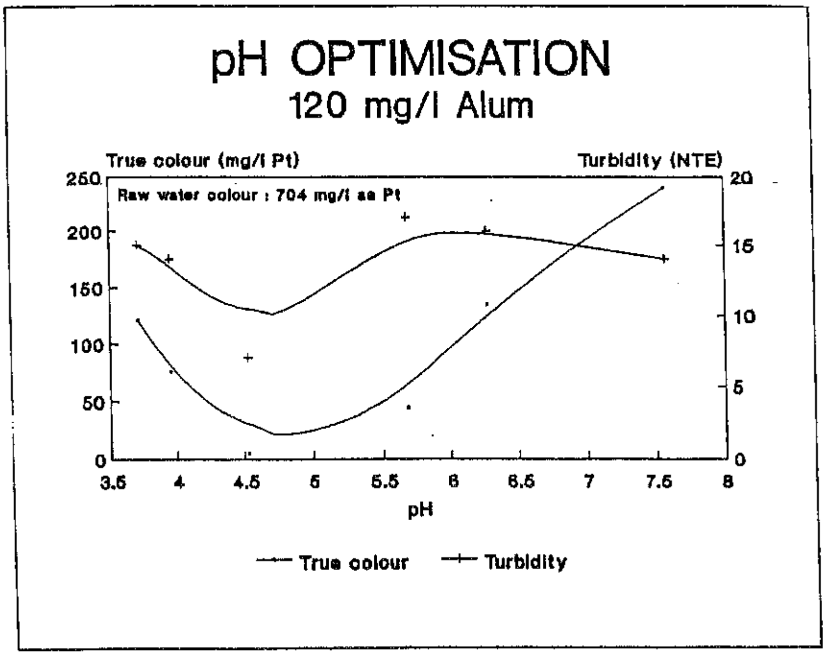

POLYELECTROLYTE OPTIMISATION
50 mg/l Alum
True colour (mg/l Pt)
Turbidity (NTE)
Raw water colour : 73 mg/l as Pt
20
15
10
5
0
20
15
10
5
0
0
2
4
6
8
10
Polyelectrolyte dosage (mg/l)
True colour
Turbidity


POLYELECTROLYTE OPTIMISATION
50 mg/l Alum
True colour (mg/l as Pt)
Turbidity (NTE)
Raw water colour : 73 mg/l as Pt
0
1
2
3
4
5
6
0
0.05
0.1
0.15
0.2
Polyelectrolyte dosage (mg/l)
True colour
Turbidity


POLYELECTROLYTE OPTIMISATION
40/50 mg/l Alum at pH 5,3
True colour (mg/l as Pt)
Turbidity (NTE)
Raw water colour : 73 mg/l as Pt
40 mg/l Alum dosage
50 mg/l Alum dosage
0
5
10
15
20
25
0
0.1
0.2
0.3
0.4
0.5
0.6
Polyelectrolyte dosage (mg/l)
True colour
Turbidity
True colour
Turbidity


pH OPTIMISATION
100 mg/l Alum
True colour (mg/l Pt)
Turbidity (NTE)
Raw water colour : 629 mg/l as Pt
120
100
80
60
40
20
0
20
15
10
5
0
3.8
4
4.2
4.4
4.6
4.8
5
5.2
pH
True colour
Turbidity


pH OPTIMISATION
100 mg/l Alum
True colour (mg/l Pt)
Turbidity (NTE)
Raw water colour : 640 mg/l as Pt
30
25
20
15
10
5
0
5
4
3
2
1
0
4.6
4.7
4.8
4.9
5
5.1
5.2
5.3
5.4
5.5
pH
True colour
Turbidity


pH OPTIMISATION
120 mg/l Alum
True colour (mg/l Pt)
Turbidity (NTE)
Raw water colour : 704 mg/l as Pt
250
200
150
100
50
0
20
15
10
5
0
3.5
4
4.5
5
5.5
6
6.5
7
7.5
8
pH
True colour
Turbidity

ANNEXURE D

PROPOSED STANDARD MEASUREMENT PROCEDURES FOR THE CHARACTERISATION OF RAW COLOURED WATERS IN SOUTH AFRICA AND FOR TREATMENT QUALITY CONTROL

The following sections give the proposed standard procedures for physical and chemical analyses of raw coloured waters, which are required for characterisation of the raw water sources for the planning and design of new water purification plants, or for the upgrading of existing treatment plants. More detailed analyses of the raw waters for research purposes, *e.g.* determination of humic and fulvic acids, molecular size distributions (fingerprints), TOC, DOC or COD measurements, or total trihalomethane formation potential (TTHMFP) are not included.

The procedures are also valid for analysis of physical and chemical quality parameters of water samples taken after unit treatment processes, and of the final water, which is needed for plant operation and quality control.

For each analysis, an abbreviated description of the proposed method of the determination is given, with a reference to the detailed procedure (such as Standard Methods for the Examination of Water and Wastewater). This is followed by recommended procedures for sampling and storage of the water samples for the particular analysis.

1. COLOUR (APPARENT AND TRUE)

Procedure for apparent colour

The unfiltered water sample is analysed by means of a spectrophotometer at a wavelength of 455 nm. The meter scale is precalibrated in colour units based on the APHA Platinum-Cobalt Standard (adapted from *Standard Methods*) of 1 colour unit being equal to 1 mg/ℓ platinum as chloroplatinate ion.

Procedure for true colour

The sample is filtered through a 0,45 μm filter membrane and the colour of the filtrate determined in the same way as above.

Reference

Standard Methods for the Examination of Water and Wastewater
(18th Edition, 1992): Part 2120

Sampling and storage

Collect samples in clean plastic or glass bottles. Fill completely and cap tightly. Avoid excessive agitation or prolonged contact with air. Samples should be analysed as soon as possible after collection but can be stored at least 24 hours by cooling to 4°C. Warm to room temperature before doing the test.

The different methods and standard procedures for laboratory and field measurements of colour in water samples are given below.

Laboratory measurements

a. Colour-comparison tubes (Nessler tubes)(visual measurement)

A stock solution of K_2PtCl_6 is prepared that contains 500 mg/ℓ of platinum. Cobalt chloride is added to provide the proper tint. The stock solution has a colour of 500 units, and a series of working standards is prepared from it by dilution. Colour-comparison tubes, commonly called Nessler tubes, are used to contain the standards. This method has the serious disadvantage of subjectivity.

b. Spectrophotometer (photometric measurement)

An alternative is to calibrate spectrophotometer readings with standard platinum-cobalt standards and take sample colour readings directly with the spectrophotometer. Readings are taken at a wavelength of 455 nm. Adapted spectrophotometer instruments are available that give direct Pt-Co colour readings (*e.g.* Hach 2000 or 3000, etc).

Field measurements

a. <u>Proprietary devices</u>

A number of instruments have been developed for the measurement of colour to eliminate the need for renewing standard colour solutions from time to time. Most of these instruments employ coloured glass disks which simulate the various colour standards when used in the particular instrument.

In South Africa the Hach Colour Comparator is often used at water treatment works treating coloured water.

b. <u>Coloured glass disks</u>

Field kits have been developed employing aluminium tubes with glass windows on each end and a series of coloured glass disks. Two tubes are used. One contains the sample and the other distilled water. The coloured glass disks are placed over the end of the tube with distilled water until a combination is found that appears to have a colour similar to that of the sample. The method is recognized as standard for field use.

2. UV ABSORBANCE

<u>Procedure</u>

Measure the absorbance with a spectrophotometer at a wavelength of 254 to 300 nm. A standardised method for UV measurement is given in the 19th Edition of Standard Methods (1995).

<u>Sampling and storage</u>

Collect samples in clean plastic or glass bottles. Fill completely and cap tightly. Avoid excessive agitation or prolonged contact with air. Samples should be analysed as soon as possible after collection but can be stored at least 24 hours by cooling to 4°C. Warm to room temperature before doing the test.

3. TURBIDITY

Procedure

Measure the nephelometric turbidity of the sample by using a turbidimeter consisting of a nephelometer with a light source for illuminating the sample and one or more photoelectric detectors with a readout device. Calibrate and do measurements according to the operating instructions of the instrument.

Reference

Standard Methods for the Examination of Water and Wastewater
(18th Edition, 1992): Part 2130

Sampling and storage

Determine turbidity on the day the sample is taken. If longer storage is unavoidable, store samples in the dark for up to 24 hours. Do not store for long periods because irreversible changes in turbidity may occur. Vigorously shake all samples before examination.

4. pH

Accurate measurement of pH in carbonate species deficient waters is difficult due to the low buffer capacity of these waters. Unless appropriate procedures are adopted it is possible to obtain measurement errors of up to one pH unit with associated high errors in the alkalinity determination and calculated acidity. In low alkalinity waters where pH is used to determine acidity, the measurement should be to within 0,1 pH unit of the true value.

Procedure

Loewenthal, Wiechers and Marais (1986) suggested the following procedure for measurement of pH of carbonate species deficient waters:

a. Standardize the pH probe against National Bureau of Standards (NBS) buffers.

b. Rinse the glass and reference probes thoroughly with distilled water.

c. Probes must be dipped into at least three separate 200 mℓ samples of the water to be analysed and kept in each sample for about 30 seconds with gentle stirring of the sample. This adapts the probe to the low carbonate species low buffering capacity water, and the liquid junction effect is stabilized. Repeat until agreement is reached between successive samples.

d. Probes must be inserted into the test solution, and the solution gently stirred for at least 3 minutes before taking the reading - in low buffered waters the response of the electrode system is slow.

e. Probes should be regularly cleaned by dipping into hydrochloric acid for about 30 seconds and then well rinsed. This is particularly needed for meters used to measure coagulation pH values.

f. The porous plugs used for liquid junctions tend to clog and give erroneous readings because the flow of the filling fluid is too slow. This can be detected by the large change in pH reading caused by stirring the water. Reference electrodes with ground plastic junctions (orion) are generally free of this effect and can easily be flushed. Hach also make electrodes giving a free flow of filling liquid.

Sampling and storage

Samples should be collected in clean plastic or glass bottles or beakers and analysed immediately.

Note:

See also Section 7.2.1 (c).

5. ALKALINITY

As indicated above, for carbonate species deficient waters accurate measurement of alkalinity is not straightforward for the following reasons:

- alkalinity of these waters is very low, often less than about 5 mg/ℓ as $CaCO_3$. An error in the alkalinity determination by titration to an incorrect pH endpoint due to the misapplication of colorimetric methods, or an error in the pH reading, or wrong choice of endpoint pH, can give rise to an error of up to four hundred percent in the alkalinity value; this in turn gives rise to errors of the same magnitude in the calculated value for acidity.

- accurate measurement of pH in carbonate species deficient waters is difficult due to the extremely low buffer capacity of these waters (see 4 above).

Procedure

Standard Methods for the Examination of Water and Wastewater
(18th Edition, 1992)

The normal procedures for alkalinity measurement of carbonate species deficient waters (*i.e.* raw coloured water) are inadequate for research purposes. Loewenthal, Wiechers and Marais (1986) proposed that to obtain accurate values of alkalinity in raw coloured waters, the Gran titration technique should be used. This technique is explained in detail and calculation examples given in the WRC report (Loewenthal, Wiechers and Marais, 1986).

6. CALCIUM

Reference

Standard Methods for the Examination of Water and Wastewater
(18th Edition, 1992):   Part 3500-Ca

7. MAGNESIUM

Reference

Standard Methods for the Examination of Water and Wastewater
(18th Edition, 1992): Part 3500-Mg

8. CONDUCTIVITY

Reference

Standard Methods for the Examination of Water and Wastewater
(18th Edition, 1992): Part 2510

9. IRON

Reference

Standard Methods for the Examination of Water and Wastewater
(18th Edition, 1992): Part 3500-Fe

10. MANGANESE

Reference

Standard Methods for the Examination of Water and Wastewater
(18th Edition, 1992): Part 3500-Mn

11. ALUMINIUM

Reference

Standard Methods for the Examination of Water and Wastewater
(18th Edition, 1992): Part 3500-Al

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ANNEXURE E

PROCEDURES FOR PERFORMING COAGULATION BEAKER TESTS

COAGULATION BEAKER TESTS

Taken from

AMERICAN WATER WORKS ASSOCIATION
MANUAL OF WATER SUPPLY PRACTICES AWWA M37 (First Edition)(1992)

Operational Control of Coagulation and Filtration Processes

and

AMERICAN SOCIETY FOR TESTING AND MATERIALS
Designation D 2035 - 80 (Reapproved 1995)

Standard Practice for Coagulation-Flocculation Jar Test of Water

A detailed description of the procedure to be followed when performing coagulation beaker tests is given below. However, the procedure can be simplified for routine use and for process control purposes. The simplified procedure is given in paragraph 6 in this Annexure.

Because of the fact that the coagulation process forms the backbone of plants treating coloured water, the beaker test for coagulation control plays an important role in ensuring that the plant functions cost-efficiently, and that a high quality final water is supplied to the consumer. For this reason, the beaker test is discussed in some detail below.

1. APPARATUS

Beaker test equipment consists of beakers to hold the water, a mechanism to turn the impeller, the impeller, reagent racks for the chemicals to be dosed, and laboratory equipment to analyze the results. A description of each of these items and their role in the jar test procedure is given below.

1.1 Beakers

The main function of the beaker is to hold the water during the beaker test procedure so that observations can be made. Various types of containers have been used, including standard 1-ℓ glass beakers and square 2-ℓ containers. These are discussed below to show the advantages and disadvantages of each.

a. 1-ℓ circular

The 1-ℓ glass beaker has been around the longest and is the smallest and least expensive container. However, it has several disadvantages. First, it holds very little water. Consequently, a minor error in a chemical dosage can result in a large error in actual dosage, which will be further exaggerated when applied to a full-scale plant. Second, the beaker is circular and the stirring mechanism causes the water to rotate with the paddles thereby reducing the amount of actual mixing during rapid mixing and flocculation. The 1-ℓ beaker provides a limited amount of water for evaluation. If several tests are to be run on the water after the beaker test procedure, there may not be enough sample left to work with. Finally, the glass beaker does not provide for a good sampling point to develop settling velocity data.

b. 2-ℓ circular

The 2-ℓ glass beaker provides a larger volume of sample for the beaker test and later analysis. The main disadvantage of the 2-ℓ beaker is the circular shape that, like the 1-ℓ beaker, allows the water to rotate with the stirring mechanism. This allows the stirring mechanism to operate at a higher velocity gradient at a given speed than when no stators are used. A sampling siphon can also be added but with some effort. It should be noted that care must be exercised when working with stators, because they often interfere with the paddles and with sample withdrawal. These beakers are acceptable if stators are added.

c. 2-ℓ square

A square 2-ℓ beaker has been used recently as an alternative to the glass beakers discussed previously. The commercially available square jars are fabricated by cementing together sheets of plexiglass. The square plexiglass jars have a number of advantages over the glass beakers. These include the following:

- the square configuration reduces the rotation of the water during mixing, making stators unnecessary
- the thicker wall and lower heat conductivity of the square plexiglass beaker over the glass beaker reduce the change in water temperature during the jar test
- the plexiglass jars are less fragile and can be repaired if accidentally damaged
- they can be equipped with a sampling port for collection of settling velocity data.

1.2 Stirrer

A stirring mechanism is needed to turn the impellers. There are two basic types of stirring mechanisms in use: gear-driven and magnetic-driven.

The gear-driven unit has a variable-speed motor that turns four to six gears. The motor(s) and gears are located above the beaker test containers so that the shafts for the impellers extend down into each beaker. Units are available that can be controlled from about 10 to 300 rpm.

The magnetic-drive unit works on the same principle as a magnetic stirrer plate. The paddle contains a magnet that turns as the metal under it rotates.

Either type of unit may be used for beaker testing. The magnetic-drive unit has the advantage of providing open space above the beakers to add chemicals. It is also possible to construct a beaker stirrer by using one or more variable-speed mixers. Units can be purchased that will operate over a broad rpm range, allowing for more intensive rapid mix. They offer the advantage of testing different mix intensities simultaneously since the stirrers are individually controlled.

1.3 Reagent racks

Reagent racks are used as means of introducing each test solution to all beakers simultaneously. There should be at least one rack for each test solution or suspension.

2. REAGENTS

The small quantities of water that are utilized for beaker testing necessitate that the chemical stock solutions be diluted. The amount of dilution required is dependent upon the dosage and the minimum volume of chemical that can be accurately measured. However, the effectiveness of the metallic salt coagulants has sometimes been shown to vary with the dilution strength. Generally, dilution of these treatment chemicals improves their effectiveness. The exception is dilutions that result in less than a 0,1 percent solution where the coagulant may lose effectiveness due to hydrolysis. In addition, dilute solutions will frequently degrade over time. Therefore, it is recommended that dilute stock solutions be made up on a daily basis.

The procedures for preparing stock solutions of the common coagulant chemicals are described in the following paragraphs.

2.1 Aluminium sulphate (alum)

Stock solution for beaker testing:

a. Dry alum, $Al_2(SO_4)_3.14H_2O$:

- Use a 1-ℓ volumetric flask.
- Dissolve 10 g in 600 mℓ distilled water.
- Fill to the 1-ℓ mark.
- Solution contains 10 000 mg/ℓ or 10 mg/mℓ (1% solution).
- Therefore, 1 mℓ of the stock solution added to a 2-ℓ jar will equal a 5 mg/ℓ alum dose.

b. Liquid alum:

- The strength of stock solutions as delivered should be verified.
- The solution should be diluted with distilled water to contain 10 000 mg/ℓ or 10 mg/mℓ (1% solution).
- 1 mℓ of the stock solution added to a 2-ℓ jar will then equal a 5 mg/ℓ alum dose.

2.2 Ferric chloride

Stock solution for beaker testing:

a. Dry ferric chloride (anhydrous):

- Use a 1-ℓ volumetric flask.
- Dissolve 2,93 g in 600 mℓ distilled water.
- Fill to the 1-ℓ mark.
- Solution contains 1 000 mg/ℓ or 1 mg/mℓ of Fe.
- Therefore, 1 mℓ of the stock solution added to a 2-ℓ jar will equal a 0,5 mg/ℓ ferric chloride dose expressed as Fe.

NOTE: *On an equal molar basis, 1 mg of Fe is about the same as 5,4 mg of alum.*

b. Liquid ferric chloride:

- Liquid ferric chloride varies by the manufacturer, and analyses of the iron content should be made.
- It should be diluted to contain 1 000 mg/ℓ or 1 mg/mℓ of Fe.
- 1 mℓ of this solution added to a 2-ℓ beaker will then equal a 0,5 mg/ℓ ferric chloride dose expressed as Fe.

2.3 Ferric sulphate

Stock solution for beaker testing:

a. Dry ferric sulphate (anhydrous):

- Use a 1-ℓ volumetric flask.
- Dissolve 3,57 g in 600 mℓ distilled water.
- Fill to the 1-ℓ mark.
- Solution contains 1 mg/mℓ of Fe.
- Therefore, 1 mℓ of the stock solution added to a 2-ℓ jar will equal a 0,5 mg/ℓ ferric sulphate dose expressed as Fe.

b. Liquid ferric sulphate:

- Liquid ferric sulphate also varies by the manufacturer, and analyses of the iron content should be made.
- It should be diluted to contain 1 000 mg/ℓ or 1 mg/mℓ of Fe.
- 1 mℓ of this solution added to a 2-ℓ beaker will then equal a 0,5 mg/ℓ ferric sulphate dose expressed as Fe.

2.4 Polyaluminium chloride

The currently available polymeric aluminum coagulants are produced using a number of different methods. Therefore, general statements regarding preparation of the stock solution and effective pH range are not appropriate. Rather, the reader is referred to the individual manufacturer's information.

The dosage requirements for the aluminum and iron salts are controlled by the amount of particulate matter in the water and the amount of dissolved organics (total organic carbon [TOC] or more correctly dissolved organic carbon [DOC]). Of the two (amount of particulate matter in water and amount of DOC), it is the DOC that influences the dosage requirements the most. A good starting point for estimating the range of coagulant dosages to be evaluated is 5 to 10 mg of alum or 1 to 2 mg of ferric as Fe per mg of DOC.

3. pH CONTROL

If the coagulant reaction is allowed to occur at nonoptimized pH conditions when using aluminium and iron salts as the primary coagulants, the quality of the treated and filtered water will be degraded by the presence of undesirable concentrations of dissolved aluminum and iron. The metallic salt coagulants are generally more susceptible to loss of effectiveness with nonoptimized pH conditions than the polymers.

Often the pH is controlled only by the dosage of the coagulant applied. If the water treatment plant operates this way, the beaker test should be conducted the same way when the chemical dosage or the routine treatment of water is aimed to be optimized.

It is possible, however, for the properties of the raw water to be such that optimum treatment is achieved at a pH significantly different from that obtainable from the coagulant alone. A beaker test series will quickly demonstrate this. There could be cases where it will be more cost effective to adjust the raw water pH with another chemical (acid or base) to achieve the best pH for the particular coagulant of choice. Again, the beaker test is perhaps the most valuable tool in the operator's tool chest for rapidly determining the best combination of coagulants and other chemicals to achieve the most cost-effective and process-efficient reaction pH.

Adjusting the pH during a beaker test can be a hectic task as anyone who has tried to measure and adjust the pH in six jars during a 1 min. rapid mix can attest to. The easiest and generally most accurate way is to predetermine the required acid or base dose. This is done by taking a small sample of raw water, say 100 to 200 mℓ, and adding the desired coagulant dose to be equivalent to the dose in the 1-ℓ or 2-ℓ beaker. Place the sample on a standard stirrer and titrate with acid or base, recording the dose to reach the desired pH level. Determining the acid or base doses to reach different pH levels for one coagulant dose can be done in one titration. If it is desired to determine the acid or base dose for different coagulant concentrations, the test needs to be repeated. With this information, the proper volume can be premeasured and fed to the beaker during, before, or after coagulant addition. The pH at the end of the rapid mix phase should still be measured and recorded.

It should be noted that one of the difficulties of keeping the chemical conditions in the beakers similar to the plant is that carbon dioxide exchange in the atmosphere is usually quicker in the jars. This means that the pH will vary in the jars to a greater extent than in the plant.

Common chemicals

The chemicals that are normally utilized for pH control include

- Lime
- Soda ash
- Sodium hydroxide (caustic soda)
- Hydrochloric acid
- Sulphuric acid

In many cases, the use of caustic is more convenient for jar testing. Lime is a suspension that requires continuous stirring. Caustic soda can be used as a dissolved liquid without stirring. The +2 charged calcium ions associated with lime have been shown to act as a coagulant aid. Consequently, its use for increasing the pH may have a slightly more beneficial effect than the use of caustic where the sodium ion has only a single positive charge. However, in many cases these benefits are negligible. Consequently, if a base is required for pH adjustment, the use of either is generally acceptable, regardless of what the full-scale facility is using, and the use of caustic is much easier.

Once the dose of lime or caustic has been established, the following conversion factors can be used to switch between them if the water treatment plant uses a chemical other than that which is used in the beaker test series:

- mg/ℓ 100 % CaO = mg/ℓ $CaCO_3$ x 0,56
- mg/ℓ 100 % $Ca(OH)_2$ = mg/ℓ $CaCO_3$ x 0,72
- mg/ℓ 100 % Na_2CO_3 = mg/ℓ $CaCO_3$ x 1,06
- mg/ℓ 100 % NaOH = mg/ℓ $CaCO_3$ x 0,80

Sodium hydroxide (caustic soda). For beaker testing, a 0,1 N solution of sodium hydroxide is generally sufficient for pH adjustment. Reagent-grade sodium hydroxide is usually supplied in pellet form. To prepare a 0,1 N solution:

- add 200 to 500 mℓ of distilled water to a clean 1-ℓ volumetric flask
- drop in a magnetic stir bar and place flask onto a magnetic stirrer
- weigh out 4 g of the sodium hydroxide pellets onto an aluminum or plastic weighing dish
- pour all of the pellets into the volumetric flask. Mix at medium speed until all of the pellets dissolve
- remove the magnetic stir bar and fill the volumetric flask to the mark with distilled water
- cap and shake for at least 1 min
- the strength of the stock solution will be 4 000 mg/ℓ or 4 mg/mℓ as 100 percent NaOH. Therefore, 1 mℓ added to a 2-ℓ jar will be equivalent to a dose of 2 mg/ℓ.

Procedure for drawing up titration curves

Fill glass beaker with the water to be tested. Using a magnetic stir bar, place the beaker on a magnetic mixer and turn up the mixing speed so as to form about a 13-mm vortex. With a pipette, dose the beaker with the desired coagulant dose. Insert the pH electrode into the beaker and titrate from a burette the lime or other chemical to adjust the pH to the desired level. (If limewater is used, it is important to use a small concentration so the lime is dissolved or uniformly suspended). Record the volume of lime or other chemicals added as a function of pH. Scale up the desired chemical dose by the ratio of the volume of sample in the beaker to the 2-ℓ size.

4. PREPARATIONS FOR PERFORMING BEAKER TESTS

Before performing the beaker test, label all reagents and mix them thoroughly with magnetic stirrer and stir bar. Place the beakers of reagents near the multi-jar stirring mechanism in the order that they are to be used. Label all glass pipettes and put them in the corresponding reagent beakers. Decide on chemical dosages before the beaker test begins. Record them on the data sheet and put the sheet in an easily accessible location. Analysis equipment such as turbidimeters or spectrophotometers should be ready for use, since initial measurements such as turbidity and colour should be taken prior to the initiation of the jar test.

The beakers and paddles of the multi-jar stirring mechanism should be cleaned by wiping with a damp cloth and rinsing with warm tap water in between each test to remove any polymer residue. Similarly, pipettes used for dispensing a polymer should be thoroughly rinsed once a day or immediately if a different polymer is used. This may be accomplished by inserting the tip of a large squeeze bottle filled with hot water into the large end of the pipette and flushing with large amount of water. Occasionally, it may be necessary to acid wash the pipettes with 1N acid to remove any residual polymer.

When pipetting any particular chemical to a large number of jars, it is convenient to use one or two large pipettes (filled prior to the start of the jar test). Each pipette should have a three-valve rubber bulb so that a number of accurate doses can be dispensed before refilling the pipette. There may be a need to dilute a chemical to decrease the likelihood of measurement error when pipetting.

Load the test chemicals in the reagent racks. Use one rack for each series of chemical additions. Make up each tube in the rack to a final volume of 10 mℓ, with water, before using. There may be a situation where a larger volume of reagent will be required. Should this condition prevail, fill all tubes with water to a volume equal to the largest volume of reagent in the reagent rack.

5. DETAILED BEAKER TEST PROCEDURE

a. Collect enough water to fill the jars. Measure and record all initial parameters of interest (temperature, pH, turbidity, colour, etc.) from the head of the treatment plant or sample location.

b. Pour 1 litre or 2 litre of sample into each beaker.

c. Position the beakers under the multi-stirrer so they are centered with respect to the impeller shaft.

d. Lower the impellers so that each impeller is about one-third from the bottom of the jar.

e. Begin rapid mix period based on the predetermined speed and duration to simulate full scale.

f. Using the reagent rack, dispense the desired doses of coagulant simultaneously to each of the beakers.

g. To each of the beakers, add lime or other chemical used for pH control.

h. Continue rapid mix as required to simulate full scale. If in-line mixing is used in the plant, this chemical dispensing should be done as quickly as possible.

If plant conditions are not being simulated, a rapid mixing speed of 100 rpm and 2 minutes duration is often used.

i. Reduce mixing speed to simulate slow mixing conditions during flocculation in the full-scale process. Flocculate for the time necessary to simulate full scale.

If plant conditions are not being simulated, a slow mixing speed of 20 to 40 rpm and 10 to 20 minutes duration is often used.

j. Stop the mixer, pull up the paddles, and allow sedimentation to occur. The time of settling must be adjusted to simulate plant settling as much as possible using the graphs described earlier. Usually collecting samples at 2, 5 and 10 min. and at the time equal to the plant overflow rate is desirable. If only data at the plant overflow rate are desired, then only one sample at that time needs to be collected.

k. Withdraw samples for desired analyses (turbidity, true colour, pH, etc.). Sample withdrawal may be accomplished either by the use of a syringe or fixed sampling port. The first 5 millilitre of sample taken from a fixed port, however, should be discarded before using the sample to measure for turbidity or colour. When using a syringe, samples should be taken from the same depth as with the fixed port. The syringe should be rinsed with distilled water before sampling from a different jar.

A sufficient supply of 50-mℓ beakers or 30-mℓ plastic cups must be maintained for catching both the flush and the subsequent sample separately. With some practice and with the assistance of a timekeeper, accurate control of times can be obtained. Precise settling velocity values may be determined by making allowance for changes in depth in the beaker due to withdrawal of samples. Since only about 100 mℓ is taken from the beaker for testing and the resulting error at a 1-cm/min. velocity is less than 10 percent, it is not necessary to apply this correction.

6. SIMPLIFIED BEAKER TEST PROCEDURE

a. Use 1 litre circular glass beakers for the coagulation tests.

b. Fill the first glass beaker to the 1 litre mark with the raw water and place on a magnetic stirrer. Induce rapid mixing at around 300 rpm. Insert the probe of the pH meter in the beaker to measure the pH.

c. Add the predetermined amount of coagulant to the beaker.

d. Add the pH adjustment chemical (lime or sodium hydroxide) in small increments to the solution until the target pH is obtained (after about 1 to 2,5 minutes). Continue with rapid mixing for a further 30 seconds.

e. Take the beaker with water and put it on a Phipps and Bird (or similar) stirrer and insert the stirrer blade in the water. Stir slowly at 25 rpm for 20 minutes.

f. At the end of the flocculation period, the stirrer blade is lifted out of the beaker and the sample allowed to settle for 30 minutes.

g. On completion of the settling period, supernatant samples are withdrawn just below the water surface with suitable syringes. A portion of the sample is used directly for determination of turbidity, while the rest of the sample is filtered through a 0,45 micron membrane filter and subject to analysis for colour, UV absorbance, DOC and metals. (For DOC measurement, contamination of the filters must be avoided - rinse the filter with two small lots of sample before using the filter).

h. When the first sample is put on the Phipps and Bird stirrer, a second sample can placed on the magnetic stirrer and steps (b) to (g) repeated, using a new coagulant dosage and/or target pH value.

i. Repeat for all the required coagulant dosages and/or pH values tested for.

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ANNEXURE F

CHEMICALS USED IN COLOUR REMOVAL TREATMENT PLANTS

1. COAGULANTS

1.1 Aluminium sulphate (alum)

Appearance:	Off-white powder to kibbles (liquid alum also now available)
Al_2O_3 (solid):	17 % (m/m)
Al^{3+} (solid):	8,5 % (m/m)

Reactions:

Aluminium salts dissociates in water to yield the trivalent ion, Al^{3+}. These ions then hydrate to form the aquometal complex $Al(H_2O)_6{}^{3+}$. This complex then passes through a series of hydrolytic reactions in which H_2O molecules in the hydration shell are replaced by OH ions. In this manner a variety of soluble species are formed, some of which contain one aluminium ion (mononuclear) such as $Al(OH)^{2+}$ and $Al(OH)_2{}^{+}$, while some may contain more than one aluminium ion (polynuclear species), for example $Al_8(OH)_{20}{}^{4+}$.

Although some of these products have only one or two positive charges, they are quite effective as coagulants, because they adsorb strongly onto the surface of most negative colloids.

The formation of the various hydrolysis species, as well as the charge on the hydrolysis products, are functions of pH. Hydrolysis products can form in a limited pH range only, because the solubility increases at low and high pH values. For this reason, aluminium sulphate, when used alone without pH adjustment, is not an effective flocculant for waters with a low alkalinity, such as the Cape coloured waters.

In cases where the buffer capacity of the water is low, lime is generally added, which reacts with the $Al_2(SO_4)_3$ as follows:

$$Al_2(SO_4)_3 + 3Ca(OH)_2 \rightarrow 2Al(OH)_3\downarrow + 3CaSO_4$$

Sodium carbonate may be used to achieve the same result, but without an increase in permanent hardness:

$$Al_2(SO_4)_3 + 6Na_2CO_3 + 3H_2O \rightarrow 2Al(OH)_3\downarrow + 3Na_2SO_4 + 6CO_2\uparrow$$

Trivalent aluminium ions accomplish destabilization by three mechanisms:

(a) adsorption and charge neutralization;

(b) chemical reaction with humic materials; and

(c) enmeshment in a sweep floc.

As stated previously, hydrolyzing metal ions can produce coagulation of colloidal particles by a combination of adsorption and enmeshment. With Al^{3+} ions, the chief mechanism at pH values below the isoelectric point would be adsorption, while enmeshment would be the main mechanism at pH values above the isoelectric point.

Handling and dosing:

A facility for solid handling is required along with stirred make-up tanks for dissolution. Liquid alum is less corrosive than ferric chloride and stainless steel materials can be used.

1.2 Ferric salts

Ferric salts will dissociate in water to yield trivalent Fe^{3+} ions, in a manner similar to the dissociation of aluminium sulphate. These ions will then hydrate to form aquometal complexes, such as $Fe(H_2O)_6^{3+}$. During hydrolytic reactions the H_2O molecules in the hydration shell are replaced by OH^- ions. A variety of soluble species, both mononuclear, $Fe(OH)^{2+}$ and $Fe(OH)_2^+$, and polynuclear, $Fe_8(OH)_{20}^{4+}$ can be formed. These products are quite effective as coagulants because the adsorb strongly onto the surface of negative colloids.

The formation of the various hydrolysis species, as well as the charge on the hydrolysis products, are functions of pH. Fe^{3+} hydrolysis products can form over a much wider pH-range than for trivalent aluminium, because the precipitate is insoluble at high pH-values, and also at pH-values lower than for aluminium.

Like aluminium ions, trivalent ferric ions accomplish destabilization of colloids by three mechanisms:

(a) adsorption and charge neutralization; and

(b) chemical reaction with humic materials; and

(c) enmeshment in a sweep-floc.

As was indicated in a previous section, hydrolyzing metal ions can produce coagulation of colloidal particles by a combination of adsorption and enmeshment. In the case of Fe^{3+} ions, the chief mechanism at pH values below the isoelectric point would be adsorption, while enmeshment would be the main mechanism at pH values above the isoelectric point.

1.2.1 Ferric chloride

Appearance:	Dark orange/brown solution
$FeCl_3$:	42,5 - 44,0 % (m/m)
Fe^{3+}:	Approx. 14,5 % (m/m)
SG (20°C):	1,45

Reactions:

As with $Al_2(SO_4)_3$, the relevant reactions will be as follows:

$$FeCl_3 + 3H_2O \rightleftarrows Fe(OH)_3 \downarrow + 3HCl$$
$$FeCl_3 + 3(HCO_3)^- \rightarrow Fe(OH)_3 \downarrow + 3Cl^- + 3CO_2 \uparrow$$
$$2FeCl_3 + 3Ca(OH)_2 \rightarrow 2Fe(OH)_3 + 3CaCl_2$$

Supply:

Commercial ferric chloride is supplied as a solution containing 43 % (mass per mass) or 62,5 % (mass per volume) $FeCl_3$. It also contains free hydrochloric acid. Therefore the chloride content of the solution should be determined before the exact dosage can be calculated from the increase in the chloride content of the water after dosing.

Handling and dosing:

A handling and dosing facility suitable for a corrosive liquid is a prerequisite for ferric chloride use. Heavy duty HDPE tanks are recommended for bulk storage. Compatible fibreglass or rubber lined steel tanks can also be used. $FeCl_3$ should be metered undiluted through a corrosion resistant positive displacement dosing pump with subsequent dilution at the dosing point if deemed necessary for rapid dispersion through the water body. The in-line dilution should be a minimum 10% solution strength. No metals should be in contact with ferric chloride.

1.2.2 Ferric sulphate

Appearance: Dark red/green/brown solution

$Fe_2(SO_4)_3$: 37,5 % (m/m)

Fe^{3+}: Approx. 11 - 12 % (m/m)

SG (20°C): 1,35

Handling and dosing:
Less corrosive than ferric chloride and stainless steel can be used.

1.3 Polyaluminium chloride (PACℓ)

This is a broad based term that is used for a number of aluminium based compounds produced via different manufacturing processes resulting in polymeric aluminium chloride derivatives with Al_2O_3 contents between 10 and 25 % (m/m).

Reactions:

PACℓ products exhibit similar characteristics in clarification performance in the role of a primary inorganic coagulant. It is effective with negligible pH depression and alkalinity consumption. It can be used over a wide pH range, generally as a blend with an organic coagulant. Usually less effective than metal salts for removing humic materials.

Handling and dosing:

PACℓ is slightly corrosive but can be handled in high grade stainless steel. It should be metered undiluted through corrosion resistant positive displacement dosing pumps with subsequent dilution at the dosing point if deemed necessary for rapid dispersion through the water body. A minimum 20 % solution strength is recommended.

1.4 Sodium aluminate

Sodium aluminate is a mixture of Na_2O and Al_2O_3. It is an alkaline salt, and is commercially prepared by stabilizing alumina with sodium hydroxide.

In practice, sodium aluminate is often used together with aluminium sulphate, thus reducing the amount of acid or lime required for pH adjustment. When combined with alum the hardness of the water is not increased as much as with alum alone.

Appearance:	White or off-white powder or concentrated solution
$Na_2Al_2O_4$ (solid):	70 - 80 %

Reactions:

When dissolved, this flocculant dissociates to give an alkaline solution of sodium and aluminate, $Al(OH)_4^-$, ions. If acidified, the latter are successively converted to $Al(OH)_3$ (insoluble), $Al(OH)_2^+$, $Al(OH)^{2+}$ or Al^{3+} , depending on the pH.

As alum is acidic and sodium aluminate alkaline, when used in conjunction in a suitable ratio, a much smaller amount of lime is needed for pH adjustment. The sodium aluminate and lime should be added to the water before the alum.

2. COAGULANT AIDS / FLOCCULANTS

2.1 Polyelectrolytes

A number of synthetically prepared polyelectrolytes are available on the market. They are chiefly polymerized amines and acrylamides with molecular masses of up to 3 000 000. These include cationic, nonionic and anionic types. Some of these types have been cleared by the health authorities for use as flocculants in the preparation of water for drinking purposes, but others have not been given certificates of approval, because they are considered detrimental to health. Before any such product is marketed as a flocculant for drinking-water, clearance should be obtained by the supplier from the health authorities.

When used, these polyelectrolytes should be dosed in small quantities (usually less than 1 mg/ℓ), because they act to bind together the floc particles formed by the main flocculant, which could be aluminium sulphate, ferric chloride or ferric sulphate.

The use of polyelectrolytes may be beneficial to:

- aid rapid floc formation;
- create heavier floc particles; and
- reduce the unit treatment cost in some cases, when used in combination with other flocculants.

Certain types of polyelectrolytes may, however, be used as primary coagulants, but not for colour removal.

Care must be taken not to overdose polyacrylamides as filter runs can be drastically shortened and filters clogged.

Because polyelectrolytes are organic compounds, overdosing could stimulate the growth of fungi in filter beds as well as distribution systems. Normally, prechlorination would prevent the growth of fungi but, as chlorine has a detrimental effect on the flocculation properties of polyelectrolytes, prechlorination is not recommended.

2.2 Activated silica

Activated silica has been in use as a coagulant aid for many years. It is prepared by carefully acidifying (HCl, H_2SO_4, CO_2, etc.) a saturated solution of sodium silicate (Na_2SiO_3) to the stage where polymeric silica begins to form. If acidification is carried too far, amorphous silica will precipitate. If stopped in time and left to stand for approximately two hours, the mixture may solidify by gelation. However, if the solution is diluted to relieve the state of supersaturation, the polymeric silicates will be preserved and the coagulative properties could be retained for several weeks. Activated silica is best prepared at the site where it is to be applied. Chlorine can also be used to activate the sodium silicate:

$$Na_2SiO_3 + Cl_2 \rightarrow SiO_2 \text{ act.} + NaOCl + NaCl.$$

The NaOCl is beneficial when prechlorination is desirable.

2.3 Clays

In cases of low turbidity, it is sometimes considered expedient to introduce a clay to increase the number of suspended colloids, and thereby to assist in the removal of the initial suspended material by enmeshment in a sweep floc, also giving a heavier floc.

Kaolinite (also referred to as kaolin) is a type of clay which is not readily obtained in a dispersion fine enough to remain in suspension for a relatively long time. On the other hand, bentonite will produce a better suspension, but because of its specialized properties, it is relatively expensive.

3. LIME

As mentioned in Chapter 6, the quality of lime used at the treatment plants that were surveyed varies considerably from supplier to supplier and also over time. During the project samples of lime used at the treatment plants were taken (at different plants and at different times) and analysed with respect to quality. The analyses were performed by the Division of Water, Environment and Forestry Technology of the CSIR in Pretoria. The results of the analyses are given in the table below to give an indication of the variability of the quality of lime used at the Cape water treatment plants.

	TRANS-HEX Mining	NDOLA	LIMBUX	K.M. Port Elizabeth	P&B Lime Works (ex Robertson)	P&B hydrated lime	ULCOLIM hydrated lime	NDOLA hydrated lime	NDOLA hydrated lime
Calcium hydroxide as CaO (%)	60,2	61,6	70,3	58,0	53,2	46,6	49,4	50,1	60,0
Calcium carbonate as CaO (%)	9,9	10,1	3,08	13,1	13,8	16,9	15,4	18,4	9,0
Total available lime as CaO (%)	70,1	71,1	73,3	71,1	67,0	63,5	64,8	68,5	69,0
Total available lime as $Ca(OH)_2$ (%)	96,5	94,7	96,8	94,0	88,5	83,9	85,6	90,5	91,2
Fe (mg/g)	0,70	1,27	0,79	6,6	2,8	1,79	2,01	0,75	0,36
Mn (mg/g)	0,20	0,05	0,10	0,2	0,1	0,05	3,55	0,07	0,00
Ca (mg/g)	413	436	400	480	420	488,5	477,32	489,93	497,10
Mg (mg/g)	16,0	11,3	4,32	11	30	16,54	16,73	11,97	4,00

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A Seminar / Workshop on **Treatment of Coloured Water for Potable Use** was held in Mossel Bay on 21 - 23 October 1996. On the last day of this workshop, two and a half hours were allocated to a strategic planning session. The objective of the session was to afford all the users of research on coloured water treatment the opportunity to raise issues which they personally perceived to be problems requiring solution in the treatment of these types of water.

The session was facilitated by Dr Gerhard Offringa of the Water Research Commission. Issues were elicited from each attendant. The issues were listed, categorised where required and main research priorities allocated.

The following list gives the issues and problems raised at the strategy planning session, and which requires further research. The first eight issues in the list are given in order of priority as determined during the session, with the remainder listed in random order. The first two issues were considered especially important as requiring further research.

1. Characterization and removal of unwanted organic components

2. The management of water works sludges:

   - Disposal of sludge to sewage
   - Choice of coagulant
   - Dewatering of sludge
   - Recovery of coagulants
   - Utilization of sludge (agriculture, by-products)
   - Toxic components in sludge (*e.g. Mycrocystis*)

3. Disinfection of coloured waters and disinfection by-products

4. Treatment of coloured water for small communities

5. Education of coloured water treatment plant personnel

6. Use of alternative unit processes in the treatment of coloured water:

   - Dissolved air flotation
   - Membranes
   - Advanced oxidation
   - Ultraviolet radiation / catalyst
   - Series filtration
   - Sirofloc treatment
   - Treatment by activated carbon
   - Declining rate filtration

7. Correct and repeatable measurement of pH

8. Stabilisation of treated coloured water

9. The upgrading of existing water works

10. Dealing with variable water quality and flows

11. Issues regarding the design of coloured water treatment plant and equipment:

    - Sedimentation tanks
    - Timeous linking with plant personnel and chemical suppliers
    - Operator-friendly design
    - Design for future plant expansion
    - Use of alternative materials of construction
    - Flexibility of design for flow, quality and other changes
    - Provision of a clear and concise operating manual

12. Tastes and odours in treated coloured waters

13. Selection of the appropriate coagulant, flocculant, dosing point and mixing energy

14. Limiting of metal residuals

15. Influence of raw water temperature on the treatment process

16. Minimum requirements for analytical equipment used in the treatment of coloured water

17. Foam formation

18. Health aspects of polyelectrolytes

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